SENSORS, CONTROLS, MONITORS AND MEASUREMENT TECHNIQUES FOR AGRICULTURAL PROBLEMS

FINAL REPORT -- EES

PROJECT NO. E-600-902
(FY's 72-73 and 73-74)

By

J. C. Meaders
W. H. Hicklin
T. P. Lang
G. W. Leddicotte

A Report of Research Carried Out
By The
APPLIED SCIENCES DEPARTMENT
ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
Atlanta, Georgia 30332

Date: February 21, 1975

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ABSTRACT

This report summarizes the results of one of the studies initiated in 1973 by the ENGINEERING EXPERIMENT STATION, at the Georgia Institute of Technology, to relate to, service and support Georgia Industry.

Based on the premise that the EES has some expertise in almost any type of SENSOR technology known, the study had as its principal interest an exploration of the potentials of developing new "sensors" or adapting existing technology to meet some of the identifiable needs within the agricultural industry of Georgia. In addition, some consideration was given to exploring the usefulness of other scientific and technical capabilities of the STATION to aid in such problems.

Research staff members of the STATION's Applied Sciences Department assigned to this project have met with administrators, scientists and technologists of many of the major agricultural interests in Georgia. As a result of these meetings, a large number of problems have been identified. A "state-of-the-art" search of the applicability of SENSORS (as well as any complementary technology) for such problems was initiated and its results recorded. In an effort to prove the worth of this activity, experimental work was carried out to develop and apply a prototype sensor (a vitality probe) to the problem of "peach-tree decline" and the development of technology (in this instance, an X-ray fluorescent analysis system) for the problem of determining micronutrient elements (such as Mo, Fe, Cr and Cu) in water, soils and agricultural crops.

In this report, the description of the experimental work activities is prefaced by (1) a summary of the more recent advances in the use of sensor technology and chemical and physical measurement techniques for agricultural problems, and (2) by some general statements about the relative importance of the electrical properties of plant tissues to the development of the "peach-tree decline" probe. The report also includes a brief description of the current use of equipment and technology for the harvesting of crops, fruits and

nuts and the control of insect pests about cattle barns and feedlots—two problems in the agricultural industry that could use EES assistance.

The results of this project and the information that has become available to the EES staff members concerned with it suggest that there is a need for the ENGINEERING EXPERIMENT STATION to become more seriously involved in work with the agricultural industry of Georgia. The industry has many problems and its scientists and engineers could use the special resources the STATION has to aid them in meeting the industry's present and future technical and economic needs.

1.0 INTRODUCTION

The ENGINEERING EXPERIMENT STATION has, within most of its units, some expertise in almost any type of science and technology known, and is readily able to assess the potentials of applying such resources to problems in any segment of Georgia Industry. Hence, early in 1973, a decision was made to carry out an investigative program on how the EES could best relate to, serve and support the agricultural industry of Georgia.

The objectives of this project became specific in that its principal tasks were to be (1) the identification of problem areas in agriculture that might be solved by the use of sensor technology or by some chemical or physical measurement technique, (2) establish an experimental base and carry out work on selected problem areas that could lead to the development of a sensor or measurement technique for that particular problem and (3) generally assess the impact of such developments on the agricultural industry. These project objectives were met by carrying out these following tasks:

a) a "state-of-the-art" study of the use of sensors, controls and monitors, and the applications of measurement techniques, in agriculture;
b) the development of a rapport with most of the major agricultural interests in Georgia to identify problem areas;
c) the development and testing of prototype sensors for studies of "peach-tree decline;"
d) the development of a prototype x-ray fluorescent analysis system for micronutrient elements; and
e) an assessment of other agricultural problems that could benefit from EES resources.

This investigative program was assigned to staff members from the APPLIED SCIENCES DEPARTMENT of the Engineering Experiment Station (NOTE 1-1). The information that follows summarizes their findings and the results of their research activities from the time this project was initiated in January 1973

NOTE 1-1: As applicable, recognition is given to contributions made by staff members of other EES units.

to July 1974. The report also makes some recommendations for the continuing participation by EES in such a program area.

2.0. SOME CURRENT PROBLEMS OF GEORGIA's AGRICULTURAL INDUSTRY

As this project was carried out, the Applied Science Department staff members participating in it met with administrators, scientists and technologists from some of the major agricultural research and industrial interests in the State of Georgia (See NOTE 1). Serious discussions were held with representatives from the Commissioner's Office, State of Georgia Department of Agriculture; the University of Georgia—College of Agriculture—Experiment Stations, Georgia Station, Experiment, Georgia; the Southeastern Pecan Growers Association; the Georgia Peach Council; the U.S. Department of Agriculture's Southeastern Fruit and Tree Nut Research Station, Byron, Georgia; and the Cooperative Extension Service of the University of Georgia—College of Agriculture, Athens, Georgia.

In all of these meetings, immediate recognition and acknowledgement was given to the diversity of scientific and technical talent that each group represented. Even within the agricultural groups themselves, it is recognized that no one scientist or technologist can achieve a formidable and profitable end-result for his particular problem unless he has assistance from other staff members of his organization or is aided through assistance from external organizations such as the EES. Hence, these discussions gave further emphasis to the need for the EES to maintain a strong liaison and serious program interactions with the agriculturalists.

Collectively, the results of these meetings have given strong indications that there are needs to have prevention and control technology for and/or methods to measure the effects brought about by such problems as these:

1) Fruit and nut tree decline—especially, of peach and pecan trees;
2) Nutritional, nematode and soil disease problems in orchards and field crop lands;

NOTE 2-1: APPENDIX A provides a listing of most of the agricultural farm organizations in Georgia. Periodic contact with most of these groups needs to be maintained.

3) Soil density and compaction caused by soil tillage methods;

4) The removal, or "partial destruction" of "cementing agents" that cause soil aggregates or clusters—a problem that can result from either soil organic materials in various stages of humification; the binding properties of amorphous or semi-crystalline oxides or hydroxides of iron, aluminum, silicon, manganese, titanium and/or alkaline earth carbonates; soil microorganisms; or plant root systems;

5) "Too little" or "too much" moisture to or on all kinds of plants and their growing areas;

6) All types of plant diseases;

7) Protection of field crops, and fruit and nut trees from low temperature;

8) The moisture content of grains, meat, other bulk food products;

9) Milk quality;

10) Production, storage and distribution of quality crop seeds (Georgia's Foundation Seed Program);

11) Insect control, not only for crops and forests but also for livestock and dairy cattle barns;

12) The protection of livestock and poultry from low temperatures;

13) The detection of water depletion in cropped fields;

14) The detection of land surface temperature changes and their effects on plants and crops;

15) Heating and drying of field crops, e.g. peanuts and tobacco;

16) The determination of the concentration and height of the heads of standing grain;

17) Detection of animal diseases, e.g. mastitis in bovine udders;

18) The mechanical grading of eggs;

19) The determination of seed viability and vigor, e.g. separation of living and dead corn kernels without germination;

20) The correlation of specific factors, e.g. rainfall, soil temperature, soil porosity, the presence of oxygen and/or carbon dioxide, in the topsoil and subsoil of growing areas and their relationship to growth and viability or disease states;

21) Harvesting and storage of most agricultural crops;

22) The accumulative effects of pesticides and herbicides on crop yields;

23) The effects of pesticide residues on any food material;

24) The potential release of certain natural elemental species in the top-soil or subsoil of growing areas by the use of certain types of fertilizers or by fertilization methods that could lead to the production of toxicity to/or the creation of toxicants in a crop species;

25) Understanding chemical interactions of herbicides, pesticides and food additives with each other or with natural elements of the environment to produce biologically active compounds to form mutagens and carcinogens in living systems;

26) Phytotoxicity of seed dressings—too much/too little;

27) Establishing the hazards to shoots, blossoms and fruits that arise from fungicides sprayed on fruit trees; and

28) The establishment of continuous or disruptive lengths of illumination to correct diapause effects (spontaneous dormancy) in seedlings and mature plants.

Our literature survey—summarized in Chapter 3—provided us with information about research that is being carried out on other and similar problems in agriculture. Our presentation of this information in the manner shown below is intended to be both additive to the above information and a further stimulus for using the expertise and resources of the ENGINEERING EXPERIMENT STATION in aiding Georgia agriculturists. The references cited, (1), (2) etc. contain usable information that can serve as a base for any actions EES might take in any of these problem areas:

a) Seasonal activity of insects on fruit trees and cereal grains—e.g., cankerworm on apple trees (1) and cereal bugs (2);

b) The influence of relative humidity or moisture on the absorption of nutrient elements—e.g., Mg and Zn by soybeans (3) and the solubility of Zn in soils and its absorption by corn (4);

c) The effect of temperature change on enzyme activities (5,6), photosynthesis (7), nitrate absorption (8,9), plant growth activities (10,11) and transpiration (12);

d) Moisture diffusion patterns in plants—e.g., through grain (13), or peanuts (14);

e) Absorption and effects of excessive soil mosture and water as related to seed growth (15), plant physiological activities (16,17), plant diseases (18,19) and nutrient uptake (20);

f) Soil moisture management—e.g., in the irragation of corn and soy bean crops (21,22), fruit orchards (23) and controlled planting plots (24);

g) The absorption and conversion of nitrogen in relation to the way a nitrogen fertilizer is applied—e.g. by wheat (25,26), or by apple trees in winter (27);

h) The physiological activity of plants—e.g., the growth and movement of wheat (28) and rice root systems (29), or the development of wheat mitochondria (30);

i) Solar radiation effects on plants (31-35);

j) The absorption kinetics by plants of phosphorus and/or phosphates—e.g., by wheat (36,37) or grasses (38);

k) Methods of fertilizer application and their influence upon nutrient uptake and plant growth (39-41);

l) The adaptability of plants to drought conditions and the use of ameliorative actions (42-45);

m) The effect of seasonal variations on plant physiological activities—e.g., the production of estrogens in herbage (46) or the foliar uptake of mineral salts by citrus trees (47);

n) Photo-respiratory phenomena and rate of respiration in plants—e.g., oxygen uptake and carbon dioxide release by maize (48);

o) The relationship of temperature and water status on plant growth—e.g., of cotton (49);

p) The absorption of applied nutrient elements by plants and trees—e.g., by wheat (50), fruit trees (51,52), barley (53), or herbage (54);

q) The assimilation of nutrients under winter temperatures (55);

r) Effects of day length and seasonal changes on the photochemical activity of plants (56), on root cell mitotic activity (57), or on shoot size and flower quality (58);

s) The effect of light (blue, red, infrared) on plant growth (59) and enzyme activity (61);

t) Plant disease kinetics—e.g., the mechanism of mosaic virus production (61);

u) Control of plant diseases in replant sites (62);

v) The biological activity of soil microorganisms (63,64);

w) The effects of and controls for the distribution of herbicides, insecticides, and pesticides on the habitats of any plant species (65-67);

x) The effects and control of growth retardants—e.g., on plant growth mechanisms (68); and

y) Determinations of the winter hardiness and frost hardiness of plants and trees (69-72).

Some of these problem areas are pertinent to agronomy, horticulture and plant pathology. Others are related to nutrition, and still others are relevant to the harvesting, processing and distribution of specific agricultural products; and such agricultural activities as animal husbandry.

Obviously, some of these problems can be aided by sensors. While advanced chemical or physical measurement techniques or mechanical technology will be more appropriate for others. Potentially, the combination of a sensor with a chemical (or physical) measurement or mechanical handling technique could lead to useful technology for many of these problem areas.

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3.0 SENSORS, CONTROLS, MONITORS AND MEASUREMENT TECHNIQUES FOR AGRICULTURAL PROBLEMS

Scientific and technological developments since the end of World War II have shown that there are many dynamic needs to control, indicate, measure and/or record any physical, chemical or biological property of matter that could have an influence upon man and his multi-facet activities. Startling as it may be, over 50,000 different scientific and industrial instruments have been developed since 1946 to meet many of these needs. However, many more thousands will need to be developed and produced to meet the challenge of present and future science and technology.

3.1 SOME GENERALITIES ABOUT SENSORS, CONTROLS MONITORS AND MEASUREMENT TECHNIQUES

Each of us has different mental pictures of sensors, controls, monitors and measurement techniques; hence, a different concept of what each encompasses. However, the one conspicious projection is that most scientific and technological problems need such devices. To generalize, a doctor will think of a scalpel, or perhaps, an electrocardiograph; a chemist thinks of a laboratory pH meter or an infrared spectrograph; a chemical operator envisages a recording flow-meter; while an electrician assumes that his portable volt-ohm-milliammeter is one of his better tools.

In such an overview, it becomes obvious that a sensor, monitor or measurement technique must serve some goal; that is, it must be capable of detecting and measuring some phenomenon and, ultimately through auxillary capabilities, displaying the results of the measurement. As a monitoring device, it must attract the attention of someone, whether it is by means of its display unit, or by an alarm. It should produce records of such nature that not only the actual values of past measurements but also their trend can be readily visualized. A record may be one involving a time series extending over hours or days of measured values which change slowly; such a record may be complementary to or used instead of other technology to record the same or analogous data. A record may also be one of basic events in which only intermittent measurements are taken at periodic time intervals and recorded to be subsequently reused at a later time.

The record, or display, of the measured values must (1) clearly indicate the type of measurement, (2) show the value in a form in which it would actually be quoted or reported, and (3) give the relationship (or comparison) of the indicated value to a normal or limiting value, before decisions for action are taken on the basis of the magnitude of the difference. In most instances, a minimum of data processing must be supplied. If an indicator system and/or an alarm system has to be initiated, processing by a rate circuit is required.

Broadly speaking, a detector, a control or the output of an analytical instrument can be technically identical to a fully automated monitoring system. However, because it relies on the constant availability and presence of personnel to (a) interpret its indications, (b) detect dangerous trends and (c) keep records, it will be less complex and cheaper. Conversely, a monitor system, in which a detector, or control, or analytical instrument is used, will be more complex and more expensive, but it will be less dependent on staff vigilance. Which system is appropriate depends on the requirement. Sensing, measuring and monitoring installations are essentially communication systems. However clear the equipment may be technically in terms of zero stability, accuracy, linearity, or any other mechanical or electrical parameter, if it fails to communicate at the vital time, it has failed utterly.

Sensor, control and measurement technology is dependent on the detection and/or measurement of changes in temperature, humidity, density, pressure, torque and force, position, height, depth and distance. Mark and line delineations, visual acuity, tactility, color, sound, visible light, ultraviolet and infrared radiation, surface texture, chemical composition and electrical properties are also basic elements for this particular type of technology.

Some of these measurable elements - e.g., such as optical density, infrared photogrammetry, radar imagery, land surface termperature, multispectral photography - have become the basis for practical remote sensing systems that are beginning to be used in studies on natural resources and the environment.

3.2 THE "STATE-OF-THE-ART" OF DETECTION, CONTROL, MEASUREMENT AND MONITORING TECHNIQUES IN THE AGRICULTURAL INDUSTRY

Our "state-of-the-art" literature search showed that a more serious use of sensors (or controls or monitors) and/or techniques for chemical or physical measurement of a given parameter by the agricultural industry still has to be achieved. A cursory review of the literature before the mid-60's showed very few devices and techniques being used. However, since that time, a review of selected publications (see APPENDIX B for a listing) has made it possible to record at least 2600 reported items that have dealt with research and development for problems in agriculture.

A limited number of these recorded publications deal with sensor technology. These included sensors for (1) moisture, (2) humidity, (3) temperature, (4) water flow, (5) growth, (6) weight, (7) soil salinity, (8) photosynthesis, (9) gas production by microorganisms and (10) remote sensing systems. As a separate group, a number of references emphasized chemical analysis and automated laboratory equipment for specific analysis requirements. Each of the references cited in this portion of this report have been selected from this survey area to represent the work that has been carried out in this particular area of technology. Elsewhere in this report (APPENDICES C and D, respectively), some of the work on (a) harvesting technology for crops, fruits and nuts and (b) the use of ultrasonics for insect pest control is cited in order to establish some idea of what is being done in other areas that are part of the agricultural industry.

3.2.1 Sensors For Soil Moisture: Microwaves, pulsed current meters, electrical resistance, neutron scattering, tensiometers, capacitance devices and flowmeters with thermocouple outlets are some of the devices and techniques used to determine soil moisture. The references that follow are representative of most of the work carried out in this research area since 1969:

73) KRASZEWSKI, A.,"Microwave Instrumentation For Moisture Content Measurement", J. Microwave Power 8 No. 3-4: 323-335 (November, 1973).

74) KRASZEWSKI, A., "Measurement of Moisture By A Microwave Method", ROZPR Elektrotech 19, No. 1: 137-163 (1973).

75) SHALHEVET, J., "Effect of Mineral Type and Soil Moisture Content on Plant Uptake of Cesium-137", Radiat. Bot. 13 (3): 165-171 (1973).

76) VERPLANCKE, H. and Hartmann, R., "Critical Study On Nylon Resistance Units for Measuring Soil Moisture," Pedologie (PEDOAE) 19 (3): 330-356.

77) BOUYOUCOS, C. J. and Cook, R. L. "Construction, Operation and Accuracy of the Gray Hydrocal Sensor", Soil Sci. 108 (5): 309-312 (1969).

78) COLE, J. A. and Green, M. J. "Measuring Soil Moisture in the BRENIG CATCHMENT: Problems of Using Neutron Scatter Equipment in Soil With Peaty Layers", Proceedings, Wageningen Symposium, 1: 74-88 (1969).

79) KING, K. M., et al, "Soil Moisture - Instrumentation, Measurement and General Principles of Network Design", Hydrol. Symp. Proc. 6: 269-314.

80) IONESCU-SISESTI, V. and Iacobescu, S., "The Agro-Tensiometer - An Instrument For Measuring Moisture of Irrigated Soils", Inst. Agron. "N. Balcescu" (Bucur) Ser A 12: 489-506 (1969).

81) HACK, H. R. B., "An Improved Method of Soil Moisture Control With Observation on Tomato Growth and Water Uptake", J. Exp. Bot. 22 (71): 323-326 (1971).

82) RHEINISCHE KALKSTEINWERKE G. M. B. H., "Equipment to Measure Moisture By Neutrons", German Patent FR. 1515560, March 1, 1968.

83) KUZ'MICHEV, D. S., "Capacitance Method For Measuring Soil Moisture", Trans. Inst. Eksp. Meteorol. (TEMTAG), No. 29: 25-30 (1972).

84) CARY, J. W., "Measuring Unsaturated Soil Moisture Flow With a Meter", Proceedings, Amer. Soil Sci. Soc. 34 (1): 24-27 (1970).

85) DIAMOND, H., et al, "Sensor Generating An Electric Current When Exposed to Moisture", U. S. Patent 3540278. September 4, 1968.

86) Anonymous, "MAD-NIR": An Apparatus For The Measurement of Soil Moisture", FERMA INTREPRINDERA Agric. Stat. Bull. 23 (2): 22 (1971).

87) YOSHIOKA, J., "Studies on the Moisture Status of Forest Soils, I, A Ceramic Block Apparaus for Long-Term Soil Moisture Measurements in the Field and Some Results", Jap Forest Exp. Station Bull. 250: 35-32 (1973).

88) BYRNE, G. F., "An Improved Soil Water Flux Sensor", Agric. Meteorol. 9 (1/2): 101-104 (1971).

89) VISVALINGAM, M. and Tandy, J. D., "The Neutron Method For Measuring Soil Moisture Content - A Review", J. Soil Sci. 23 (4) : 499-511 (1973).

90) CARY, J. W. "Soil Water Flowmeters With Thermocouple Outputs", Proceedings Amer. Soil Sci. Soc. 37 (2): 176-181 (Mar-Apr 1973).

91) MILANOV, T., "An Instrument For Measuring Soil Moisture By Neutron Scattering", Proceedings, Wageningen Symposium, 1 : 88-95 (1969).

92) SZALAI, G. and Varga, S., "Measurement of Soil Moisture", Hidrol. Kozl. (HIDRAV) 52 (6) : 228-235 (1972).

93) COUCHAT, P. et al, "Automatic Apparatus for Neutronic Measurement of Soil Moisture", Bull. Inform. Sci. Tech. Commis. Energ. At. (Fr.), No. 172: 71-76 (1972).

94) DYAKIN, V.M., et al, "Electrolytic Sensor For Moisture Determination", USSR Patent 314128, March 12, 1969.

95) KENT, M., "Use of Strip-Line Configuration In Microwave Moisture Measurements", J. Microwave Power 8 (2): 189-94 (1973).

96) CHUDNOVSKY, A. F., "Methods and Devices For Measuring Moisture (in Soils)", Proceedings, Wageningen Symposium 2: 658-66 (1969).

97) EWING, G.W.,"Moisture Measurement", J. Chem Educ. 1968, A377-A378.

98) HAMMERLE, J. R., et al, "Moisture Sensor Placement For Regulation of Furrow-Irragation Systems", Trans. Amer. Soc. Agric. Eng. 13 (3): 303-306 (1970).

99) GARDNER, H. R., "Prediction of Water Loss From a Fallow Field Soil Based on Soil Water Flow Theory", Proc. Soil Sci. Soc. Amer. 38 (3) 379-382, May-June 1974.

100) WHITE, C. M., et al,"An Electronic Sensor and Circuit For Automatic Operations of Rainfall Shelters", Agron. J. 64 (6): 847-850 (1972).

101) LINDNER, H., "Comparative Testing of Different Soil Moisture Sensors", Arch. Acker Pflanz Bodenko 16 (12), 887-896 (1972).

102) OTA, K., et al, "Special Features of the Detecting Component of the Automatic Soil Moisture Testing Equipment For Dry-Land Irrigation", Nogydoboku-Kenkyu 40 (12): 12-14 (1972).

103) STREBEL, O., et al, "Soil-Suction Measurements For Evaluation of Vertical Water Flow At Greater Depths With A Pressure Transducer Tensiometer", J. Hydrol (Amsterdam) 18 (3/4): 367-370 (1973).

104) COUTURE, R., Hill, J. L., "Improved Resistance Moisture Measurement Techniques: Pulsed Current Meter and Wood Element Sensors", For. Prod. J. 24 (4): 17-23 (1974).

3.2.2 Temperature Sensors: Some recognition has been given to the effects of environmental temperature (both air and soil) on (a) ion transport in the plant system, (b) direction of root growth (in soil) and (c) photosynthesis. The references that follow are typical of the use of some type of temperature-measuring devices in determining these effects. One of these references (#112) has been cited to provide information on the use of temperature sensors in complement agricultural activities.

105) WALLACE, A., Abou-ZamZam, A., M.,"Effect of Temperature on Potassium and Calcium Transport From Within The Root To the Xylem Exudale of Tobacco," Plant Soil 38 (3): 687-691 (1973).

106) ONDERDONK, J., Ketcheson, J. W.,"Effect of Soil Temperature on Direction of Corn Root Growth", Plant Soil 39 (1) : 177-186 (1973).

107) FRANK, A. B., et al, "Effect of Temperature and Plant Water Stress on Photosynthesis Diffusion Resistance and Leaf Water Potential in Spring Wheat", Agron. J. 65 (5) : 778-780 (1973).

108) ONKEN, A.B., et al,"Effect of Soil Temperature and Phosphorous on Plant Growth - Uptake and Distribution of Phosphorous and Iron in Grain Sorghum", Texas A&M University College Station, Agric. Exp. Stn. Report 3251, p. 1-11 (1974).

109) SANFORD, W. G., "Effects of Root Temperature On The Uptake of Nutrients By Pineapple Roots", Proceedings, 1st Int. Hortic. Congress (1970), p. 11-12, 1973.

110) BROWN, J. M., "A Device For Measuring The Temperature of Water Soil", Ecology 54 (6) : 1397-1399 (1973).

111) SUTTON, F. and Rorison, I. H.,"The Modification of a Data Logger For the Recording of Temperatures in the Field Using Thermistor Sensors", J. Appl. Ecol. 7 (2) : 321-329 (1970).

112) Anonymous,"Quality Control-Consider Temperature Sensors", Cooking for Profit 42 (27) : 32-39 (1973).

3.2.3 Humidity Sensors: Sensors built on such devices, techniques and materials as electrical capacitance and resistance, psychrometers, lithium chloride compounds, cross-linked polystyrene resins, and an alkali metal oxide-divanadium pentoxide-silicon admixture have been used to determine water vapor and humidity at high and low temperatures. Such sensors have been used in food storage lockers, grain elevators and for measuring humidity in soil vegetative layers. The extent of this work during the last several years is summarized in these references:

113) MATTHEWS, R.P., "Two Relative Humidity Sensors Developed", Fire Control Notes 34 (2) : 7-8 (1973).

114) CARSELDINE, A. J., "A Relative Humidity Sensor For Work at Low Temperatures and High Humidity Levels - Meat Storage", CISRO Food Res. Quarterly 33 (4): 86-88 (1973).

115) KOTELNIKOV, V. and Petrov, Y., "Thinfilm Adsorption Humidity Monitor", Prib. Tekh. Eksp. (Prteaj) 6 : 182-184 (1973).

116) DAVIS, D. R. and Hughes, J. E., "A New Approach To Recording The Wetting Parameter By Use of Electrical Resistance Sensors", Plant Dis. Rep. 54 (6) : 474-479 (1970).

117) YOUNG, I. G., "High-Temperature Humidity Sensor", ISA Trans. 11 (1) : 65-76 (1972).

118) CALDWELL M.M. and Caldwell, M. L., "A Fine Wire Psychrometer For Measuring of Humidity In The Vegetation Layer", Ecology (ECOLA), 51 (5) : 918-920 (1970).

119) PANAMETRICS, INC., "Water Vapor Sensor", British Patent 1162783, August 27, 1969.

120) HERSHLER, A., "Humidity Measuring Method and Apparatus Utilizing Cross-linked Polystyrene Resin", U.S. Patent 3557619, March 17, 1969.

121) VANDERSCHUREN, H., "Properties of a Capacitive Sensor For Relative Humidity Measurements", Rev. Gen. Elec. 80 (4) : 291-298 (1971).

122) WHITEHAUS, G., "Linearizing Relative Humidity Measurements", Instru. Contr. Syst. 45 (9) : 72-73 (1972).

123) LONG, D. D.,"Low-Humidity Test Measurements", ISA Transactions 8 (1) : 71-78 (1969).

124) GRISHCHENKO, A. Z., et al, "Dynamic Characteristics of Lithium Chloride Relative Humidity Sensors", Khim. Tekhnol. (Kiev) 3 : 38-40 (1971).

125) SUMI, K., and Asakura, O., "Humidity Sensors Comprising An Alkali Metal Oxide, Divanadium Pentoxide and Silicon", U.S. Patent No. 3721631, August 16, 1971.

3.2.4 Sensors for Determining Plant Growth: Electronic sensors of several types - photoelectric cells, capacitance auxanometers - have been used to estimate the plant heights of cereal grasses, the growth of sugar beet roots and the movement of roots of oats (and their metabolism of water). The following references are examples of this technology:

126) HOSHINO, T., et al, "Evaluation of An Electronic Instrument For Estimation of Plant Height", Proceedings of the Crop Science Society of Japan 40 (4) : 545-546 (1971).

127) GORDON, S. A. and Dobra, W. A., "Elongation Responses of the Oat Shoot to Blue Light, as Measured By Capacitance Auxanometry", Plant Physicol. 50 (6) 738-742 (1972).

128) JOHNSON, W. C., and Davis, R. G. "Construction of a Sensor For Continously Recording the Change in Heights of Plants in the Field", U. S. Agric. Research Service ARS-41, 1970.

129) DAVIS, R. G. and Johnson, W. C., "A Growth Sensor for Sugar Beet Roots", Agron. J. 62 (6) : 837-838 (1970).

130) JOHNSON, W. C. and Davis, R. G., "Sugar Beet Response to Irrigation As Measured with Growth Sensors", Agron. J. 65 (5) : 789-794 (1973).

131) MEDERSKI, H. J., et al, "Water and Water Relations (To Soybean Growth)" p. 239-266 in AGRONOMY, No. 16, SOYBEANS. Improvement, Production and Uses. CALDWELL, B. E. (ed.), Amer. Soc. Agronomy, Inc., Madison, Wisconsin (1974).

132) LEWIS, III, A. J., and Haun, J. R. "Detection and Evaluation of Plant Growth Responses to Environmental Conditions", Amer J. Bot 58 (5) pg 394-400 (1971).

133) ERMAKOV, E. I., et al, "An Apparatus For The Automatic Recording of Growth Movement and Water Metabolism In Plants", Sb Tr Agron Fiz 16 : 209-215 (1968).

3.2.5 A Sensor for Determining Plant Weights: MORISHIMA (133) has recently reported on the use of an electronic device equipped with a pressure transducer to estimate the weights of hot-house grown plants. Field tests of the device are still to be made.

134) MORISHIMA, H., et al, "Evaluation of an Electronic Instrument For Estimation of Plant Weight", Natl. Genet. Mishima (Japan) Annual Report 21 : 117-118 (1972).

3.2.6 Soil Salinity Sensors: A few electronic and chemical sensors have been developed to measure and manage salinity. A salinity sensor combined with a thermocouple psychrometer has been used to measure the water and osmotic potentials of soils (136). These devices are described in these publications:

135) OSTER, J. D. and Willardson, L. S.,"Reliability of Salinity Sensors For The Management of Soil Salinity", Agron J. 63 (5) : 695-698 (1971).

136) WESSELING, J., and Oster, J. D.,"Response of Salinity Sensors To Rapidly Changing Soil Salinity", Proceedings of Amer. Soil Sci. Soc. 37 (4) : 553-557.

137) INGVALSON, R. D., et al, "Measurement of Water Potential and Osmotic Potential In Soil With a Combined Thermocouple Psychrometer and Salinity Sensor", Proceedings, Amer. Soil Sci. Soc. 34 (4) : 570-574 (1970).

3.2.7 Sensors For The Measurement of Photosynthesis: Gasometric methods and instrumentation and a light sensor technique to measure photosynthesis are described, respectively, in these publications:

138) CZARNOWSKI, M., "Instruments Used in Gasometric Methods for Photosynthesis Measurements", Biul Warzywniczy 13 : 129-159 (1973).

139) BRIGGS, W. W., et al, "Photosynthesis Light Sensor and Meter", Ecology 52 (1) : 125-131 (1971).

3.2.8 Sensors for Frost Hardiness: A few sensors, using the principles of electrical or impedance measurements, have been developed and used to determine winter injury and death to outdoor plants. Comparisons with other techniques of measuring frost hardiness are made. The following references report on some of these developments.

140) WILNER, J. and Brick, E. J., "Comparison of Radiotelemetry With Another Method For Testing Winter Injury of Outdoor Plants", Can. J. Plant Sci. 50 (1) 1970.

141) van den DRIESSCHE, R.,"Measurement of Frost Hardiness In Douglas Fur at Three Nurseries By An Electrical Method", The Forestry Chronicle, p. 65 (February, 1970).

142) EVERT, D. R.,"Factors Affecting Electrical Impedance of Internodal Stem Sections", Plant Physiol. 51 : 478-480 (1973).

143) EVERT, D. R. and Weiser, C. J.,"Relationship of Electrical Conductance at Two Frequencies To Cold Injury and Acclimation and Cornus Stolonifera Michx", Plant Physiol. 47 : 204-208 (1971).

3.2.9 Some Other Uses of Sensors: The need to measure magnetic fields in soil areas, plant water stress, the kinetic effects of excess soil moisture upon vegetation injury, soil heat dissipation, and millimeter changes in the level of water basins, plant transpiration, gas production by soil microorganisms, and the effects of natural electrical discharge (lightning) have led to the development of the sensors described in these reports:

144) VOLOKHIN, N.,"Non-Contact Electronic Magnetic Sensors", Tekh. Sel'Skom Khoz 11 : 36-37 (1970).

145) KAUFMANN, M. R. and Elfving, D. C.,"Evaluation of Tensiometers For Estimating Plant Water Stress in Citrus", Hortscience 7 (5) : 513-514 (1972).

146) COUTTS, J. R. H.,"A Simple Transducer Method For The Measurement of Millimeter Changes in Water Level", J. Soil Sci. 22 (2) : 250-253 (1971).

147) KINOSHITA, T. and Hozumi, K.,"Studies On The Physiological Mechanism of the Vegetable Injury in Excess Soil Moisture 1. Method of Polarographic Oxygen Sensors", Okitsu Tokai-Kinki Nat. Agr. Exp. Sta. Bulletin 22 : 110-118 (1971).

148) PHENE, C. J., et al,"Measuring Soil Matric Potential In Situ By Sensing Heat Dissipation Within A Porous Body. I. Theory and Sensor Construction", Proceedings, Amer. Soil Sci. Soc. 35 (1) : 27-33 (1971).

149) MEIDNER, H.,"A Critical Study of Sensor Element Diffusion Porometers (Plant Transpiration)", J. Exp. Biol. 21 (69) : 1060-1066 (1970).

150) MORESHET, S. and Yocum, C. S., "A Condensation Type Pyrometer For Field Use (for leaf resistance to water vapor diffusion)," Plant Physiol. 49 (6) : 944-949 (1972).

151) WILKINS, J. R.,"Pressure Transducer Method For Measuring Gas Production By Microorganisms", Applied Microbiology 27 (1) : 135-140 (1974).

152) PHENE, C. J., Hoffman, G. J., Austin, R. S.,"Controlling Automated Irrigation With Soil Matric Potential Sensor", Trans. Am. Soc. Agric. Eng. (Gen Ed.) 16, No. 4 : 773-776, Jul-Aug. 1973.

153) COWAN, I. R.,"An Electrical Analog of Evaporating From and Flow of Water in Plants", Planta (Berlin) 106 (3) : 221-226 (1972).

154) WORSWICK, B. J.,"Instrumental Mesaurement of Moisture Vapor Transmission Rates (of Eucalyptus Plants)", Appita. 25 (6) : 455-60 (1972).

155) DRAKE, M.,"A Tool To Evaluate Plant Nutrition", Bunda College Agric. Res. Bull. 1 : 13-14 (1970).

156) KOURTZ, P., "Lightning Sensors Tested", Fire Control Notes 34 (3) : 12-14 (1973).

3.3 THE POTENTIALS OF REMOTE SENSING SYSTEMS FOR AGRICULTURAL PROBLEMS

The usefulness of photogrammetry in mapping and land evaluation, as well as the significant results obtained from the Earth Resources Technology Satellite (ERTS) and the manned orbital laboratory, have already given agriculturists the opportunity to broaden their research for knowledge about land surface temperatures, land use, water quality, land salinity, soil moisture, characterization and yields of crops and fruit trees, foliar disease of vegetable crops, and blighting in orchards and forests. Sensors built on the principles of terrestrial photogrammetry, optical densities of photographic-imagery, ultra-high frequency radio waves, tunable lasers and infrared photography are the principle tools now being used in remote sensing systems.

3.3.1 Some Generalities About Remote Sensing Systems: The following reports are representative of those now being published on the principles and general practices used in air-borne sensing systems:

157) Anonymous,"Ahead of His Time: Invention (Infrared Detector) T. A. Simeter", Sci. Amer. 12. 227-243, December, 1972.

158) Anonymous,"Infrared Detection", Popular Science 196, 60-63 (1971).

159) LYON, R. J. P. (Ames Research Center, California), "Introductory Remarks on Infrared Sensing", in Proceedings of Conference on Oceanography From Space, Woods Hole, Mass., Aug. 24-28, 1965. Woods Hole Oceanographic Inst. Reports, 179-180, 1965.

160) HOLTER, M.R.,"Infrared and Multispectral Sensing", BIOSCIENCE 17 (6) 376-383 (1967).

161) GAUSMAN, H. W., Allen, W. A., and Escobar, D. E., "Refractive Index of Plant Cell Walls", Appl. Opt. 13 No. 1 : 109-111, January 1974.

162) HARALICK, R. M., and Kelly, G. L.,"Pattern Recognition With Measurement Space and Spatial Clustering For Multiple Images", Proceedings, IEEE 57 No. 4, p. 654-665 (April, 1969).

163) HOWELL, R. L., "Equipment and Techniques For Low-Altitude Aerial Sensing (Of Water-Vapor and Movement)", Remote Sensing of the Environment 1 : 13-18 (1969-70).

164) PEASE, R. W. and Bowden, L. W.,"Making Color Infrared Film a More Effective High Altitude Remote Sensor", Remote Sensing of the Environment 1 : 23-30 (1969-70).

165) SIMONETT, D. S. (Ed.), Remote Sensing of the Environment - - - An Interdisciplinary Journal, a quarterly publication of American Elsevier Publishing Company, Inc., New York. (See NOTE 3-1).

166) FREDEN, S. C. (Ed.), Symposium on Significant Results Obtained From the Earth Resource Technology Satellite - 1, 3-volume Report on NASA Symposium held at New Carrollton, Md. March 5-9, 1973; NASA Sci. and Tech. Inf. Off., Washington, D.C. 1973.

More recent investigations on land use, land surface temperature and moisture, salinity and temperatures of lakes, river flow regulation, characterization of water resources, detection of air and water pollutants and general ecology conditions have used remote sensing technology. Some of the methods and practices discussed in the selected references that follow have applicability to similar needs in agriculture:

167) Michigan State University, East Lasing, Report No. 18 (NASA-CR-136264),"Image Interpretation For A Multilevel Land Use Classification System", October, 1973).

168) ROSE, W. W., Thomas, D. A.,"Land Evaluation (Surface Temperature) by Remote Sensing", p. 367-375 in Land Evaluation, STEWART, G. A. (Ed.), Macmillan of Australia, 1968.

169) NUNNALLY, N. R.,"Integrated Landscape Analysis With Radar Imagery", Remote Sensing of the Environment, 1 : 1-6 (1969070).

170) BARR, D. J., Hensey, M. D.,"Industrial Site Study with Remote Sensing", Photogramm. Eng. 40 No. 1 : 79-85, January, 1974.

171) HAMID, M.A.K.,"Survey of Radiofrequency Techniques For Teledetection of Soil Moisture", J. Microwave Power 8 No. 3-4 : 217-225 (November, 1975).

NOTE 3-1: Volume 1, No. 1, 1969/70 published papers of both research and expository types that dealt with the use of remote sensor images and others remotely sensed data in scientific and practical applications in agriculture, forestry, oceanography and ecology.

172) MERRITT, E. S., Hall, C.,"Soil Moisture Estimation Applications of NIMBUS-3 HRIR D (0.7-1.3 micrometer) Observations", Report No. NOAA-731123, Earth Satellite Corporation, Washington, D.C. 1973.

173) DOLL, B.,"The Potential Use Of Polarized Reflected Light In The Remote Sensing of Soil Moisture", Army Electronics Command, Fort Monmouth, N.J., Report No. 18 (ECOM_5501), July, 1973.

174) ARMAGU, C. and Avia, J.,"Salinity, Temperature and Pollution in Lakes - Resolution By Teledetection Through Infrared Sensors", Acad. Sci. (Paris) C R Ser D 273 (21) : 1910-1913 (1971).

175) PAINTER, R. B.,"Potential Application of Satelittes in River Regulation", Water Eng. 77 No. 934; 487-491 : December, 1973.

176) ADEY, A. W., Reed, G. N.,"Radiofrequency Radiometry as a Remote Sensing Technique In Maritime Reconnaissance and Marine Sciences In a Northern Environment", Communications Research Centre, Ottawa (Ontario) Report No. 18 (CRC-TN-660), September, 1973.

177) CLAPP, J. L.,"On Multidisciplinary Research On The Application of Remote Sensing To Water Resources Problems", Wisconsin University (Madison) Inst. for Environmental Studies Report No. 18 (NASA-CR-136280), 1973.

178) CHASE, M. E.,"Airborne Remote Sensing For Groundwater Studies in Prarie Environments", Can. J. Earth Sci. 6 (4), 737-741 (1968).

179) WARREN, W. M., Wielchowsky, C. L.,"Aerial Remote Sensing of Carbonate Terranes in SHELBY COUNTY, ALABAMA", Groundwater 11 No. 6 : 14-26 Nov-Dec., 1973.

180) HINKLEY, E. D.,"Detection of Air Pollutants With Tunable Lasers", p. 24-33 in Proceedings, 1st EUR Electro-Opt Mark and Technol. Conf., Geneva, Switzerland, September 13-15, 1972; IPC Sci. and Technol. Press, England, (1973).

181) HOM, L. W.,"Remote Sensing of Water Pollutants", J. Water Pollution Control Federation 40 (10), 1728-1738 (1968).

182) SILVESTRO, F. B.,"Remote Sensing Analysis of Water Quality", J. Water Pollution Control Federation 42 (4) 553-561 (1970).

183) JOHNSON, P.G., Remote Sensing In Ecology, University of Georgia Press, Athens, Georgia, 1969.

184) COLWELL, ROBERT N.,"Remote Sensing as a Means of Determining Ecological Conditions", BIOSCIENCE 17 (7), 444-449, 1967.

185) GATES, D.M.,"Remote Sensing For The Biologist", BIOSCIENCE 17 (5), 303-307 (1967).

186) MOORE, R. K., Simonett, D. S.,"Radar Sensing In Biology", BIOSCIENCE 17 (6) 384-390 (1967).

Since 1970, there has been an increased use of remote sensing technology for agricultural problems. The references cited below are typical of these that give information about the general use of remote sensing in agriculture, and its use in investigations on the characterization of crops, crop and fruit yields, crop and forest diseases, and orchard decline (See NOTE 3-1).

187) SHAY, J. R.,"Remote Sensing For Agricultural Purposes", BIOSCIENCE 17 (7), 450-451 (1967).

188) HOLMES, R.A., MacDonald, R. B.,"The Physical Basis of System Design For Remote Sensing In Agriculture", Proceedings, IEEE 57, No. 4, p. 624-639 (April, 1969).

189) MORAIN, S. A., Holtzman, J., Henderson, F.,"Radar Sensing in Agriculture (From a Socio-Economic Viewpoint)" Proceedings of Electronic and Aerospace Systems, EASCON '70 Convention, Washington, D.C.,October 24-26, 1970, p. 280-287, IEEE 1970, New York.

190) FU, K. S.,Landgrebe, D. A., Phillips, T. L.,"Information Processing of Remotely Sensed Agricultural Data", Proceedings, IEEE 57 No. 4, p. 639-53 (April, 1969).

191) TOTTERDELL, C. J., et al,"Dual 70-mm Camera System for Remote Sensing (Of Vegetation)", Australian CISRO Field Station Record 10 (2): 73-81 (1971).

192) NEWHOUSE, M. E., et al,"Multi-Spectral Interpretation via Remote Sensing of Soils and Crops in Selected Coastal Plain Soils of Virginia", Va. J. Sci. 23 (3): 101 (1971).

193) BRACH, E. J. and Mack, A. R.,"Instrumentation Development For Characterization of Crops By Spectrophotometry", ISA Transactions 12 : 217-226 (1973).

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195) GAUSMAN, H. W., et al, "Reflectance of Cotton Leaves and Their Structure", Remote Sensing of the Environment 1 : 19-22 (1969-70).

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197) BRACH, E. J.,"Establishment of Spectral Signature of Goodland Apple by Remote Sensing", Proceedings of Aerospace Electronics Symposium, Toronto, March 15-16, 1971, Canadian Aeronautics and Space Institute, Ottawa, 1971.

198) SHARPE, P. J., and Barber, H. N.,"Near Infrared Reflectance of Colored Fruits", Appl. Opt. 11 (12): 2902-2906 (December, 1972).

199) NAKAJIMA, I.,"Research on Application of Aerial Photographs For Forest Surveys", Bull. Gov. Exp. Stn. (Tokyo) 251 : 1-253 (1973).

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203) AUSMUS, B. S., Hilty, J. W.,"Reflectance Studies of Healthy Maize Dwarf and Mosaic Virus-Infected and Helminth Sporium Maydis-Infected Corn Leaves", Remote Sensing of the Environment 2 (2), 77-81 (1972).

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206) BLAZQUEZ, C. H.,"Remote Sensing of Foliar Diseases of Vegetable Crops With IR Color Photography",Proceedings of Florida State Horticulture Society 85 : 123-126 (1972).

207) HELLER, R. C., and Bega, R. V.,"Detection of Forest Diseases By Remote Sensing", J. Forestry 71 (1): 18-21 (1973).

208) SPANN, G. W., et al,"Infrared Photography of Peach Short Life Sites in Georgia", p. 29-42 in Proceedings of 4th Biennial Workshop on Color Aerial Photography In The Plant Sciences and Related Fields, Univ. of Maine, Orno, July, 1973. (NOTE 3-1)

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3.4 SOME CHEMICAL AND PHYSICAL TECHNIQUES APPLICABLE TO AGRICULTURAL PROBLEMS

As this project was being carried out, it soon became apparent that the ENGINEERING EXPERIMENT STATION would have other resources that could be used to aid agricultural industry of Georgia. Hence, our 'state-of-the-art' review also considered an evaluation of chemical and physical analysis methods that could be used for agricultural problems. The STATION has always had extensive chemistry and physical measurement capabilities available to meet the analytical requirements of industrial, governmental and academic research. Much of this technology is practical for specific problems and could be readily adapted to become a part of many different kinds of detection, control and monitoring systems for agriculture.

The group of references cited below is only a partial listing of how some types of chemical and physical analysis methods and techniques have been used in agricultural research. Although emphasis is given to publications that describe work on (a) nutrients, (b) soil chemistry properties, (c) uptake and distribution of fertilizers by plants, (d) the effects of diapause periods, (e) elemental distribution within plants and (f) the analysis of plant protein and sugars, this approach does not cover work carried out in many other scientific disciplines that are used in agriculture - e.g. in biochemistry and phytopathology.

This listing has also been used to cite some of the types of analytical equipment that can be used as measurement devices. A few references report on the use of such equipment in automated analysis systems. Elsewhere in this report (CHAPTER 4) a summary discussion is given on the development and the use of the x-ray fluorescent system (Reference # 232) prototyped by staff members of the STATION's Applied Sciences Department.

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211) McGARITY, J. W., Myers, R. J. K.,"Seasonal Trends in the Content of Mineral Nitrogen in Solidized Soil", Australian J. Exp. Agric. Anim. Husb. 13 (63) : 423-429 (1973).

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213) STANFORD, G. et al,"Soil Nitrogen Availability Evaluations Based on Nitrogen Mineralization Potentials of Soils and Uptake of Labeled and Unlabeled Nitrogen by Plants", Plant Soil 39 (1) : 113-124 (1973).

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215) VAN GOOR, B. J.,"Penetration of Surface Applied Calcium-45 Into Apple Fruit", J. Hortic. Sci. 48 (3): 261-270 (1973).

216) MALCOSTE, R., et al," In-vivo Spectrophotometric Measurements of the Phytocrome Content of Radish Cotyledons in Darkness and Light", Physiol. Veg. 10 (3) : 575-587 (1972).

217) TAKAGI, Y. and Satake, M.,"A Low Temperature Ashing Technique for the Determination of Cadmium in Unpolished Rice by Atomic Absorption", Nippon Kagaku Kaishi 11: 2207-2208 (1972).

218) COLLINS, P. F., et al,"An Automated Procedure For The Determination of Ammonia In Tobacco", Beitr. Tabakforsch. 6 (4) : 167-172 (1974).

219) MATTERN, P. J.,"Analytical Procedures and Equipment Requirements - WHEAT", Univ. of Nebraska, Lincoln, Agric. Exp. Sta. Report 28 : 127-133 (1972).

220) HARRIS, R. B.,"How To Use Soil Tests As a Marketing Tool (For Fertilizers)", Agric. Chem. 28 (3): 12-14 (1973).

221) WALLACE, A., et al,"Measurement of Changes In Total Plant Composition of 5 Ions (Mg, Na, Ca, P,K) Simultaneously by Emission Spectrography", Commun. Soil Sci. Plant Anal. 3 (5) : 375-380 (1972).

222) RAINS, T. C. and Menis, O.,"Determination of Submicrogram Amounts of Mercury In Standard Reference Materials By Flameless Atomic Absorption Spectrophotometry", J. Assoc. Off. Anal. Chem. 55 (6) : 1339-1344 (1972).

223) McDIFFETT, W. F., et al,"Automated Continous Flow Analysis In the Study of Aquatic Systems", J. Chem. Educ. 49 (7) : 510-11 (1972).

224) JOHNSON, F. J.,"Collaborative Study of an Automated Method For Phosphorous In Fertilizers", J. Ass. Off. Anal. Chem. 55 (5) 979-983 (1972).

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226) FLORIDI, A., "An Improved Method For The Automated Analysis of Sugars By Ion-Exchange Chromatography", J. Chromatography 59 (1), 61-70 (1971).

227) CADAHIA, C., "Semiautomatic Analysis of Organic and Mineral Sulfur in Agricultural Samples With LECO Apparatus", Agrobiol. 30 (7/8): 817-826.

228) ANONYMOUS, "Automated X-Ray Inspection of Grain For Insect Infestation", Trans. Amer. Soc. Agric. Eng. (Gen. Ed.) 15, No. 6, 1081-1085 (1972).

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231) SONI, S., et al, "Electron Probe Analysis of the Distribution of Silicon in Leaf Epidermal Cells of the Oat-M Plant", Phytomorphology 20 (4), 351-363 (1970).

3.5 SOME COMMENTS ABOUT THIS "STATE-OF-THE-ART" REVIEW

We have elected to interpret our review in the manner that follows:

a) As pointed out earlier, we considered that a cursory review of the literature before the mid-1960's was adequate because most of the types of technology of interest to this project began to appear in the literature after that time.

b) The use of a selected group of scientific and technical journals - most of which were oriented to agriculture (NOTE 3-2). APPENDIX A tabulates these journals.

c) Obviously, because we had a serious interest in promoting and developing technology for the specific problem areas discussed in CHAPTER 4 of this report, our search was heavily oriented to references describing the potential use of specific sensing elements or measurement techniques in those areas we have studied. As a result,

(NOTE 3-2): The Price Gilbert Library at Georgia Institute of Technology and the services it renders through LENDS and its search services were invaluable to this study.

very little information is given about the use of such technology in the processing of agricultural chemicals, the control of food processing systems, animal husbandry, poultry-raising, and horticulture practices used in the growth of ornamental plants and flowers.

d) As a result of these search approaches, we believe that it has been possible to give recognition to a number of problem areas in agriculture that could be aided by the expertise and resources at the ENGINEERING EXPERIMENT STATION. Elaborations on this comment are given elsewhere in this report.

4.0 CURRENT EES APPLICATIONS OF SENSOR TECHNOLOGY AND MEASUREMENT TECHNIQUES FOR AGRICULTURAL PROBLEMS IN GEORGIA

As CHAPTER 2.0 of this report points out, there are many identifiable problems in the Georgia agricultural industry. The ASD research team concerned with this investigation elected to carry out experimental work in two of these problem areas, namely, those involving the need for (a) a practical laboratory or field instrument for aiding agronomists in their work on nutrient elements and (b) technology to aid in the agriculture research on fruit- and nut-tree decline, especially that of peach and pecan trees. Thus, the discussions that follow summarize much of the experimental work carried out to develop and use sensor and measurement technology in these two problem areas.

Compelementing the work described below in Section 4.3 to develop a sensor to aid in the study of "peach-tree decline" was an effort carried out by personnel in the STATION's Systems and Techniques Department to use electronic image enhancement for the same problem. Section 4.3.2 gives some generalities about this effort.

One other problem area in Georgia agriculture has been surveyed by other personnel in the STATION's S&TD. This activity, concerned with insect control by ultrasonics, is summarized in APPENDIX D.

4.1 DEVELOPMENT OF AN X-RAY FLUORESCENT ANALYSIS SYSTEM FOR THE MEASUREMENT OF MICRONUTRIENT ELEMENTS

4.1.1 Introduction: In agricultural research there is a continual awareness of the need to determine the role trace elements have as micronutrients in soil-plant systems. Similarly, these agronomic needs have a strong relationship to the concern other life sciences researchers have about the roles and effects of trace elements on the natural environment and the physiological well-being of man and animals. However, in order for these interest areas to carry out more effective study efforts, more practical and precise analytical methodology and devices need to be developed. A recent EES report summarizes the work performed to develop a prototype X-ray fluorescent analyzer (232).

232) LEDDICOTTE, G. W., et al, "A Radioisotope X-ray Energy Spectrometer System for the Determination of Some Micronutrient Elements", ENGINEERING EXPERIMENT STATION, Georgia Institute of Technology, Atlanta, Report dated June 1, 1974.

4.1.2 Principles Involved: Analytical technology, using the principal that characteristic X-rays can be induced into the stable isotopes of an element by bombarding it with sufficiently energetic radiation, offers a high potential for determining trace elements (especially those with $Z \geqq 20$) in many different types of sample materials. Conceptually, an X-ray spectrum is obtained that is characteristic of the element. An analysis of the relatively few peaks in the spectral display may be interpreted either qualitatively or quantitatively. As BIRKS (233) points out, these data usually are insensitive to physical and/or chemical environments.

233) BIRKS, L. S., "X-ray Energy Spectrometry", Applied Spectroscopy 23, 303-330 (1969).

The ASD experimental work with the X-ray energy analysis system developed in this study suggests it has these advantages over other analytical methods presently being used by researchers in the agricultural sciences: (1) non-destruction of sample; (2) minimum or no chemical pretreatment of sample prior to analysis; (3) near simultaneous determination of elements present above atomic number 20 with potential sensitivity to 10^{-12} gram (dependent upon further investigations into instrumental design); (4) analytical time required ranges from a few seconds to several minutes; (5) simplicity of analytical operation and data retrieval; (6) no requirements for specialized facilities; and (7) relative low costs for the instrumentation used, its maintenance, and for the time invested per sample analyzed.

X-ray fluorescence uses the characteristic X-rays produced as the end-products of the interactions of the atoms of an element with a source of energetic radiations. In principle, each radiation interaction with an atom ejects an electron from an inner atomic orbital of the atom. As this occurs, the atom is left in an "excited state." This "state" can persist for a very short lifetime - anywhere from 10^{-16} to 10^{-12} microsecond - after which it may decay radiatively (with the emission of electromagnetic radiations) as an outer-occupied-orbital electron undergoes rearrangements to fill the inner orbital vacancy to bring the atom back to its stable configuration (234,235). A series of electronic transitions may occur as the excited state decays.

234) BERTIN, E. P., Principles and Practices of X-ray Spectrometric Analysis, Plenum, New York, N.Y., 1971.

235) BIRKS, L. S., X-ray Spectrochemical Analysis, Interscience, New York, 1959.

To continue this explanation, X-ray fluorescence is dependent on the phenomena created as a source of radiations (e.g., electrons or gamma radiation) interacts with the atoms of an element. In effect, when an atom is exposed to radiation, one or more of its electrons are displaced from its principle quantum levels, or electronic shells (e.g., K, L, M, N, or O shells) by the photoelectric effect. At this point, the atom is an excited state and proceeds to obtain a more stable state by having the displaced electrons replaced by electrons from another quantum level.

Characteristic X-rays are identifiable according to the energy transitions producing them. X-rays of the K series arise from electron displacements, or vacancies, in the K shell. K shell vacancies can be filled by an electron from the L or M shell which give rise to K_α and K_β lines, respectively. The vacancies that occur in the L shell will be filled by electrons from the M, N or O shells to give rise to the L series of X-ray lines.

The resulting energy changes appear as photons with wave lengths (or lines) characteristic of the atom; i.e., the characteristic X-ray spectrum of each element has a simple relation to atomic number. These fluorescent X-rays are characteristic of the elements and their frequency of occurrence is proportional to the number of the specific elemental atoms present in the material exposed to the radiation source. Because the fluorescent X-rays originate from the inner electrons of an atom, they have no relationship with the chemical properties of an element or its compounds.

Another phenomena associated with photoelectric absorption is the so-called "Auger Effect." Here, the excited atom reduces its excitation by simultaneously dropping an electron from a higher shell into the vacant electronic state by ejecting another electron usually from this same higher shell. The second electron is not ejected by the photon, but emerges directly into the process of readjustment of the atom. The closer the incident radiation to the energy level's difference between two shells, the higher the probability of interaction. With higher radiation energies, the phenomena of Compton Scattering and Pair Production are observed. High atomic number (Z) elements are the easiest to detect by X-ray energy spectrometry; elements with a Z less than 12 are the most difficult to detect.

4.1.3 <u>The Units of an X-ray Fluorescence Analysis System</u>: Either (1) X-rays or gamma rays from a radioactive source, (2) a high-wattage X-ray tube, or (3) a beam of charged particles - electrons, protons or alpha particles - may be used as the source of energetic radiations. A sample specimen is placed in the path of the radiations being emitted by the source and is "excited by the incident radiation so that X-ray photons are given off. Two methods of analyzing the X-ray emissions are most frequently used, i.e., either (1) a measurement of the total number of X-rays emitted with a proportional counter or (2) the spectral distribution of X-ray energies is characterized and measured by a direct energy discrimination unit (a spectrometer) that consists of a solid state detector and its associated electronics.

Recent developments of high-resolution semiconductor detectors, such as Si(Li), and sophisticated pulse height analysis electronics have greatly increased the potentials for advancing the use of practical X-ray energy spectroscopy systems in research. As a result, all of the signals from the detector can be processed and sorted according to their energies in the memory unit of the pulse height analyzer. A continuous monitoring of the memory by a display oscilloscope allows the analyst to inspect the X-ray spectrum in real time. The spectral data may be recorded either (1) by photographing the display screen, (2) as an X-Y plot, or (3) in digital form by computer processing.

Preliminary work carried out by the Nuclear and Biological Sciences Division of the Applied Sciences Department used these criteria to develop a prototype system for agronomy research:

a. The design and construction of an analysis unit from available materials and equipment,
b. An investigation of an optimized source-sample-detector geometry,
c. The performance of tests on solid (biological tissues) and liquid (aqueous) samples, and
d. A determination of sensitivity for specific elements.

FIGURES 4.1/1 and 4.1/2 exhibit schematics of the prototype systems assembled for this study. The system used instruments and related materials available (at that time) in the Nuclear Reactor Center. The basic excitation source used in this system is a 100-mCi source of the radioisotope, 462-yr Americium-241. Some generalities about its utility in a system of the type developed here follow:

a. It is inexpensive when compared to a machine generator for X-rays;
b. It is light in weight and of small size;
c. Its output of energetic radiations is very constant and continuous; i.e., it has a high stability and can only be "turned off" by placing a lead shield over it;
d. It does not require utilities for its operations, therefore, it can be readily used in a portable analytical device.

Some disadvantages exist in the use of a radioisotopic source in that it has a limit on the overall efficiency of characteristic X-ray radiations (60 keV photons) that cannot be varied and its intensity output is not as great as that from a source of machine-generated particles.

The system is completed by the use of an energy-sensitive detector (in this instance, a Si(Li) detector), a cryogenic FET preamplifier, a linear pulse amplifier, and a pulse-height analyzer (PHA). The PHA utilizes an analog-to-digital converter which divides the pulse amplitude range (voltage) into equal increments or channels. This information is stored in a magnetic

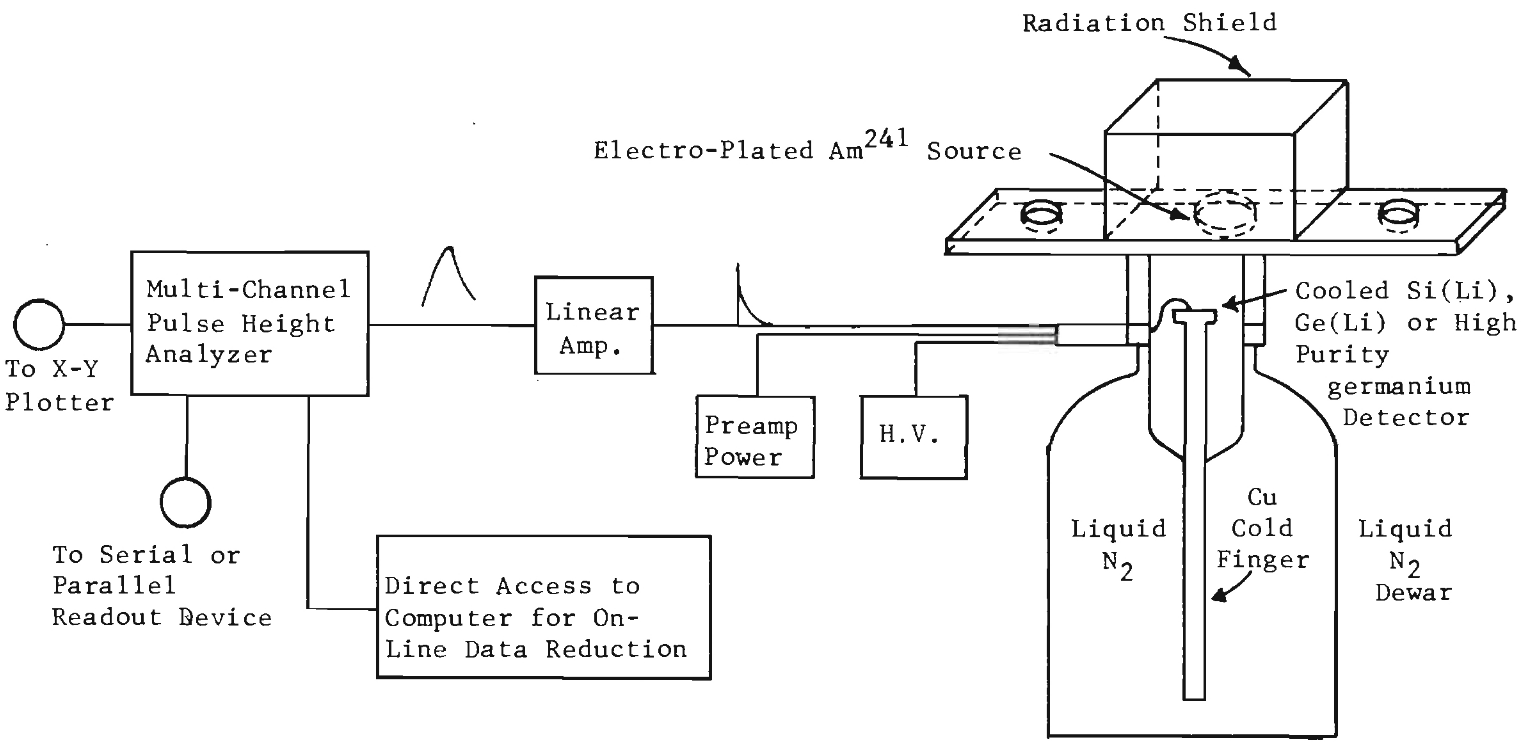


Figure 4.1/1 Schematic of Entire X-Ray Fluorescence System

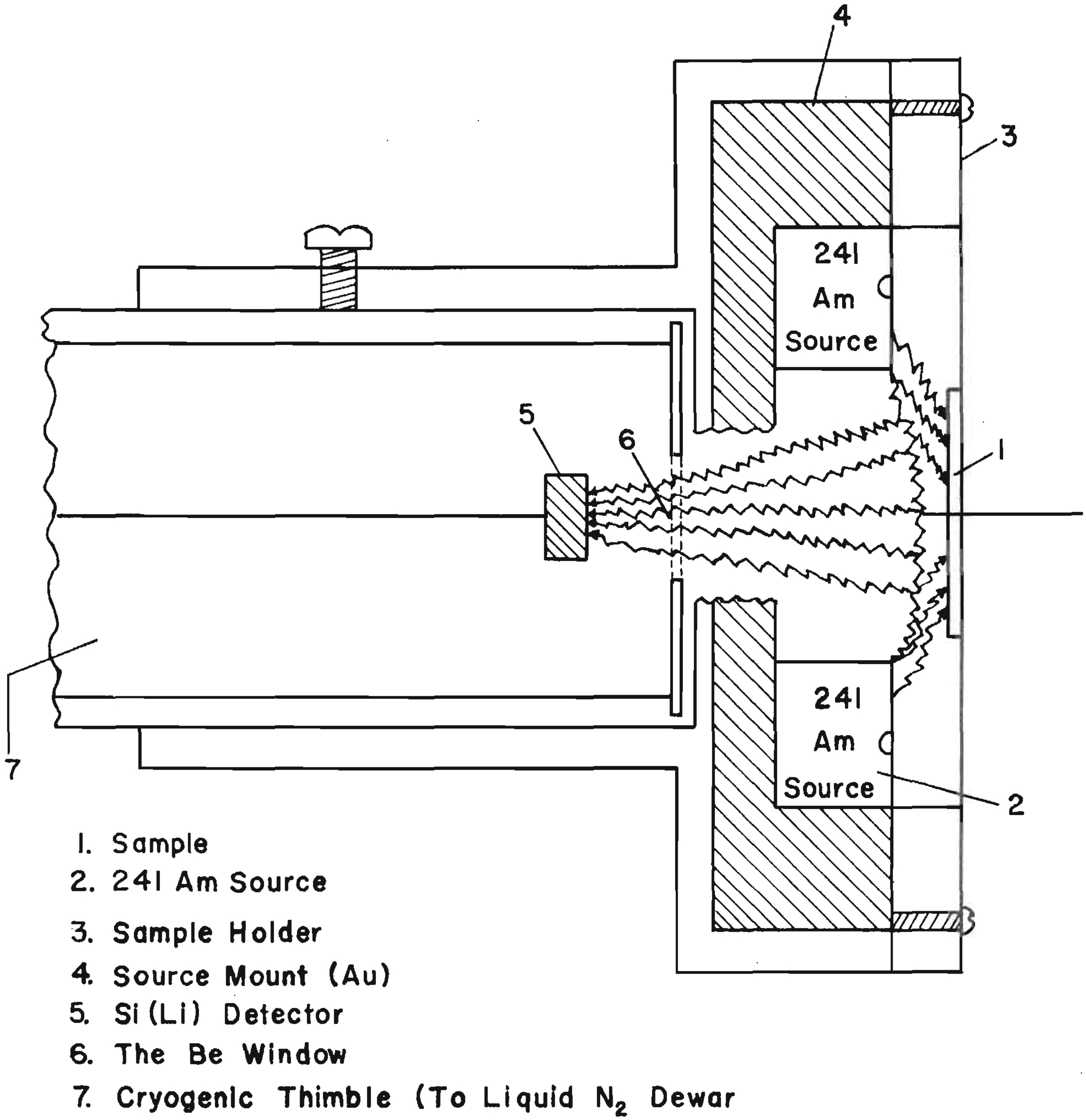


Figure 4.1/2 Sample-to-Source-Detector Arrangement.

core memory for subsequent use. The PHA has an oscilloscope display to view the data in the final stored form. A digital printer and an X-Y plotter are used to provide an analysis of the pulse-height data. (NOTE 4-1)

The spectrometer produces the data in the form of a pulse-amplitude spectrum. A typical X-ray energy spectrum is shown in FIGURE 4.1/3. The essential information in these data is contained in the peaks that are exhibited at different points on the energy spectrum. Photon energy is related to pulse amplitude (in this instance, shown as channel numbers). The intensity of a given photon energy is related to peak area. Correction for background photons in the area of each peak are made by operating the spectrometer without the sample in place for the same time interval used to measure the sample and then subtracting the total of this area from that area observed at the time the sample was measured.

The maximum energy of the peak may be determined by measuring the center of the peak on the abscissa, provided the pulse-amplitude (energy) has been calibrated. The energy vs. pulse amplitude is usually established by the use of either standard radiation sources of known X-ray energy or by injecting pulses from a calibrated pulse generator into the input of the preamplifier.

4.1.4 Some Analytical Results: FIGURE 4.1/3 is a typical X-ray spectrum of data observed in the analysis of water, soils and soybeans from controlled plots established by the Agronomy Department, University of Georgia—College of Agriculture Experiment Stations, Experiment, Georgia. In all instances, elemental concentrations were in the 1- to 10-part-Per-million concentration range.

NOTE 4-1: Other read-out devices that could be used include magnetic or punched-paper tape recorders. Integration of such devices with a computer is desirable to reduce the large amounts of data that can be accumulated in the assay of a single sample for multiple elements or the assay of multiple samples for a single element.

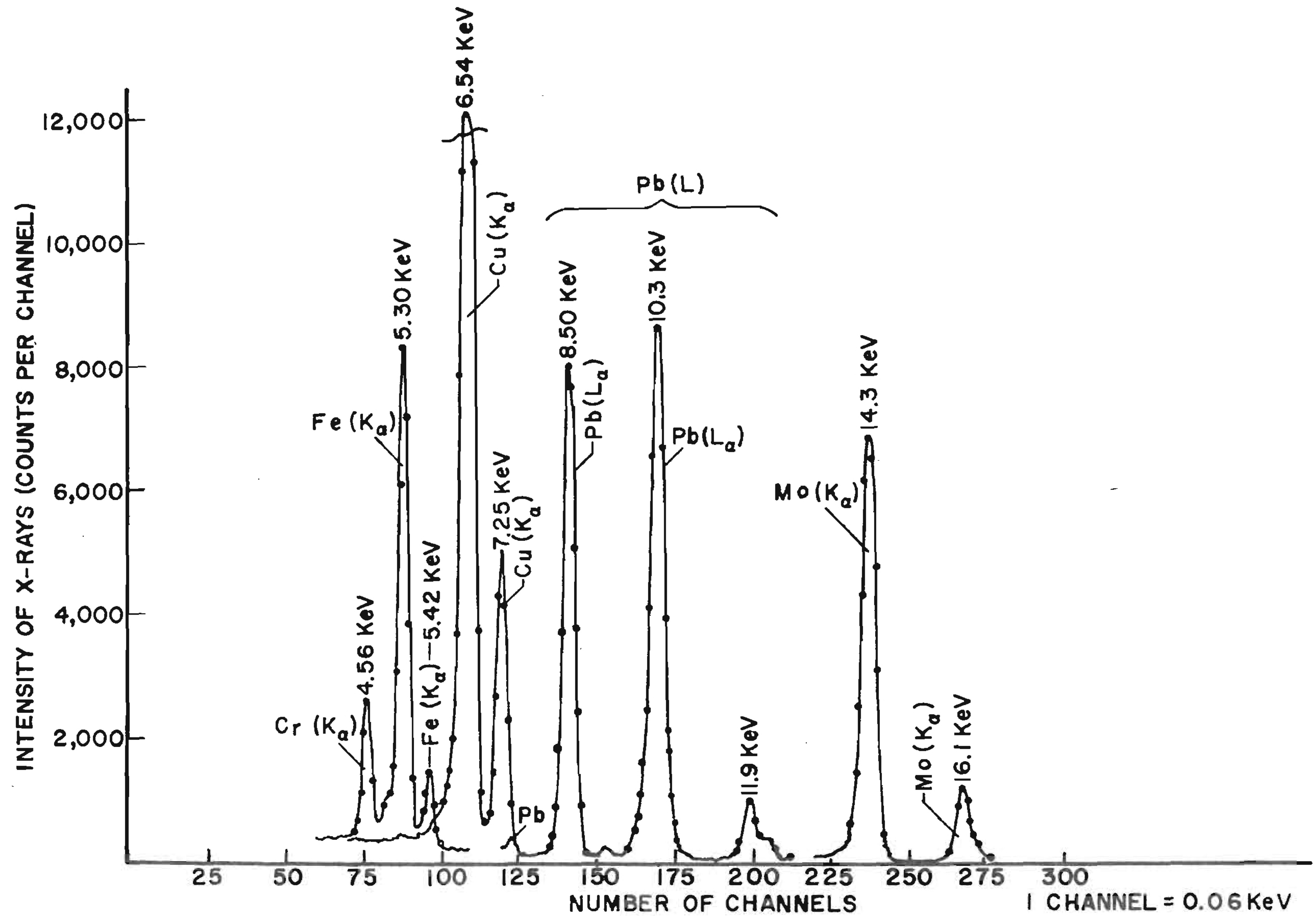


Figure 4.1/3 FLUORESCENT X-RAY SPECTRA OF SELECTED ELEMENTS.

Special emphasis was given to the determination of Mo in soybeans. The K_α peaks of Mo at 14.3 and 16.1 keV, respectively as shown in FIGURE 4.1/3, were used in extensive studies to prove the worth of the system. FIGURE 4.1/4 relates to the use of a fixed period of counting (100 seconds) to count the number of Mo X-rays produced in varied concentrations of Mo in a sample (range = 10 - 500 ppm). In actual tests of soybeans and soybean extracts, longer counting times (200 seconds or more) were used to determine Mo concentrations as small as 1 ppm.

Comparative analyses of the same sample materials by neutron activation analysis (NOTE 4-2) gave the results shown in TABLE 4/I.

TABLE 4-I: Neutron Activation and X-ray Flourescent Analysis of Soybeans for Trace Molybdenum

Sample	Mo Concentration, micrograms per gram
PH-1	3.31
-2	2.62
-3	0.89
-4	1.04
-M	1.13
PL-1	0.095
-2	0.215
-3	0.074
-4	<0.1
-M	<0.2
Extract Samples	0.18

The activation analyses of these same materials also gave results for Al, Au, Br, Ca, Ce, Co, Cr, Fe, Hg, K, La, Mg, Mn, Na, Sb, Sc, Sm, V and Zn.

NOTE 4-2: Neutron activation analysis is a technology available in the laboratories of the Nuclear Reactor Center at the Georgia Institute of Technology. In its use for trace Mo analysis, an analyst is dependent upon thermal neutron interactions with Mo atoms to produce the radioisotope Mo^{99} (6.7h) and its daughter radioactivity Tc^{99m} (6.7h). Both these isotopes emit gamma radiations that can be measured and quantitized by multichannel spectrometry.

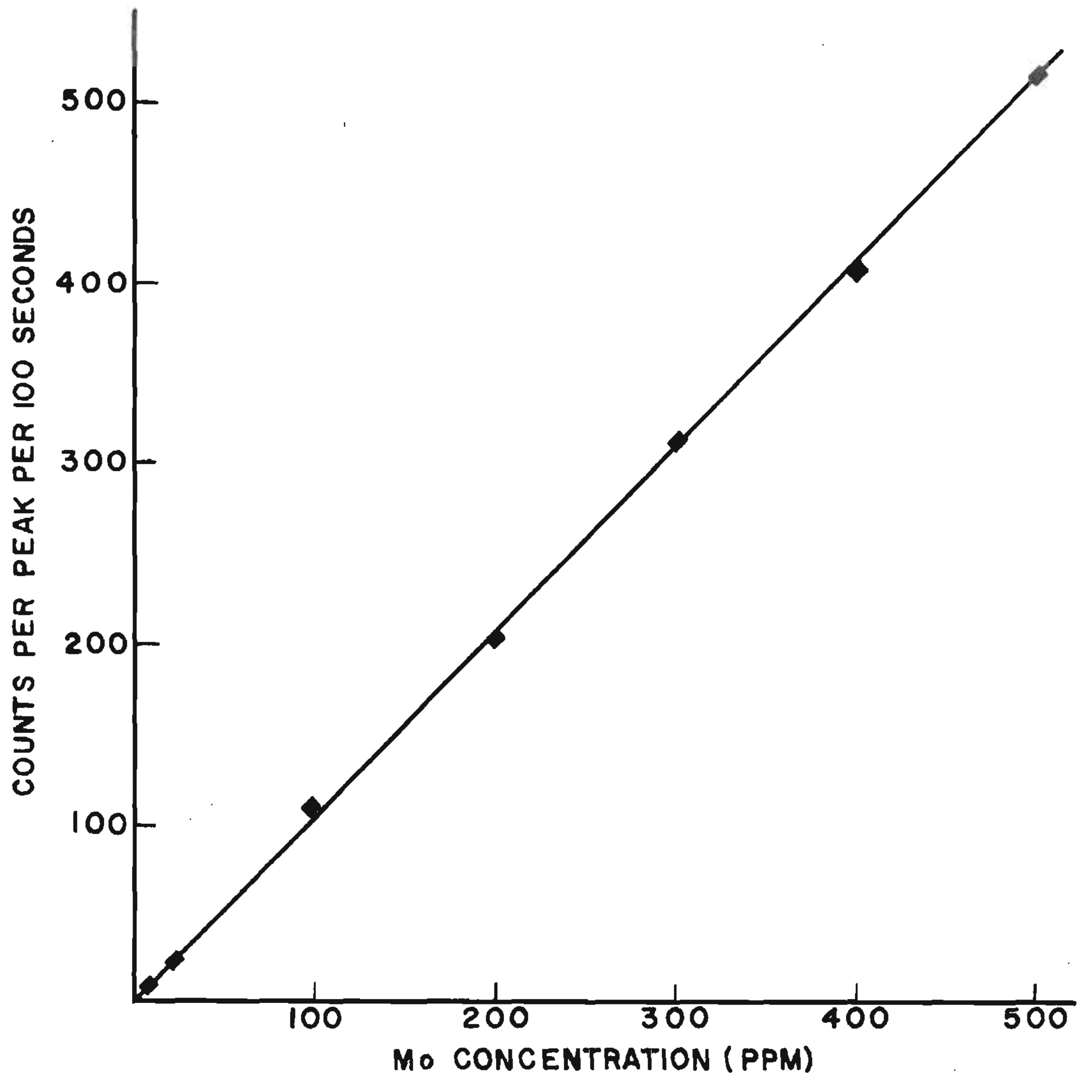


Figure 4.1/4 INTENSITY OF K_α X-RAYS AS A FUNCTION OF Mo CONCENTRATION.

4.1.5 <u>Some Conclusions About the Prototype X-ray Fluorescent Analysis System</u>: The data given in the report cited (Reference #232) and substantiated by that for trace Mo in soybeans (in TABLE 4/I) shows that this system of X-ray fluorescence analysis can have a practical use for determining many trace elements. To advance this project, at least for the needs of agronomy research, it has been recognized that it is necessary to expand its application to such other elemental species as V, Mn, Fe, Co, Ni, Se, Cd, Tl, etc. Experiments to determine the sensitivity of some of these species are already being carried out. As they are being performed, procedures to determine their presence in a mixture of elements are being developed. When necessary, chemical techniques are also being investigated to provide non-interference conditions for some elements.

The EES' work on a prototype system has already shown that

a. As an analysis system based on radioisotopic-excited X-ray fluorescence, it can be a unique and effective tool for determining trace quantities of many elements with $Z \leq 20$;

b. At least 10^{-6}-10^{-4} grams (10-100 ppm) of some elements can be determined rapidly (sometimes in time intervals of less than 100 seconds); increased sensitivity can be achieved by using longer counting periods;

c. An analysis system of this kind can be used also in the simultaneous determination of more than one element in a sample;

d. Non-destructive analyses are possible; however, when necessary, simple chemical separations can be used to separate the element of interest from the sample material before analysis by the system; and

e. It is feasible to use such a system in actual field work by the agriculturalist; commercially available battery-powered instrumentation of the type used in the laboratory makes this possible.

4.2 SENSOR TECHNOLOGY TO AID IN RESEARCH ON "PEACH TREE DECLINE"

This portion of the report gives emphasis to one of the more serious agriculture problems in Georgia. Following a general description of the problem, the remainder of this Section 4.2 describes in detail most of the experimental work carried out in the STATION's Applied Science Department to develop and use a "vitality meter." This is then followed by a general description of the STATION's Systems and Techniques Departments' work on the usefulness of photogrammetry and image enhancement technology as an aid for this problem area.

4.2.1 The "Peach Tree Decline" Problem: "Peach-tree decline" is a condition that has developed throughout the world where peaches are grown under intensive culture. It has been recognized as a problem for more than 100 years and has been described in several different ways, e.g., "the peach replant problem", "the specific peach replant disease", "the short life of peach replants", "soil sickness" and "winter injury". The "peach-tree decline" problem is usually associated with old orchard sites where a new planting closely follows removal of old trees. Generally, young trees set in old orchard sites begin to decline within two or three years and often die by the seventh or eighth year.

The problem in recent years has greatly reduced the number of bearing trees in Georgia--the average lifetime of a peachtree in Central Georgia is 6 years--and many orchards are lost within 8 years. Georgia agriculturalists report that orchards begun on "new" land have minimal problems compared to "old" orchards. However, since the short life-time as 6 years, replanting as necessary on old orchard sites because new orchard land is not always available.

The decline of peach trees has been attributed to bacterial canker, fungi, virus diseases, cold weather damage and poor cultural practices. Some scientists believe that adequate nutrition is lacking in many orchards. Others reflect on the method of pruning and time of pruning (winter vs. spring), the need to develop more hardy root stocks, control of nematodes and weeds, and methods of fertilizing. The following references are representative of some of the research now being carried out on such parameters as these:

236) BRANZANTI, E. C. and Intrieri, C., "Agronomic Aspects of Peach Tree Mortality in Ravenna: The Affects of Soil Permeability", Coltura 30 721-726 (1968) Hort. Abstr. 39: 6284.

237) GIDDIENS, J., et al, "Effect of Peach Root Residues, Lime and Supplemental Nitrogen on Survival and Yield of Peach Trees in a Decline Area", Communication in Soil Science and Plant Analysis 3(3): 253-259 (1972).

238) GAGNARD, J., et al, "Twelve-year Experiments on the Fertilizing of Peach Trees", Comptes Residues Hebdomadaivres des Sciences de l'Academie d'Agriculture de France 57(17): 1500-1544 (1971).

239) MITCHELL, P. D. and Black, J. D. F., "The Response of Replant Peach Trees to Weedicide Daily Irrigation, Nitrogen and Phosphorus", Australian Journal of Experimental Agriculture and Animal Husbandry, 11(53): 699-704 (1971).

240) MACHIA, B. M. and Campell, R. W., "Methods to Determine Low Temperature Injury to Peach Trees", Proc. Ameri. Soc. Hort. Sci. 82: 120-124 (1963).

Obviously, the rate of decline is variable with each individual tree. Hence, the premise of our study was based on the idea that a "vitality" meter that could be used in ground-truth studies (NOTE 4-3) would be a practical and, potentially, an inexpensive technology for an orchardist to survey the state of his orchard so that "declining" trees could be removed and replaced before they become a total loss and affect the profitability of his orchard. However, it must not be construed that the meter will give the "reason why" the tree was declining. We have recognized that its worth would be measured

NOTE 4-3: The work on the use of infrared photography and image enhancement techniques described in Section 4.2.3 is another approach to metering peach-tree decline problems. As a method, it is most dependent on an aerial mapping (and therefore remote sensing) of the absence or presence of foliar materials on the trees of the orchard(s) being surveyed. Although it can make extensive land area surveys, meteorological conditions affect its utility. Similarly, much data is observed and obtained in one survey and it can be quite expensive from a time and service viewpoint to process the data.

in being able to tell when a tree would become a minimal producer of fruit. Tests, sensors or other methodology must be developed to aid in giving recognition to the problem causing the "decline."

4.2.2 The Development of the "Vitality Meter": The approach taken in this development of a meter to measure the vitality (or viability) of peach trees (NOTE 4-4) is that all living materials have some natural electrical properties and that the sensing or measurement of even one of these dielectric parameters could provide some usable information to characterize some physiological property of the species being examined. However, the electrical properties of biological materials can vary widely and are most dependent on such factors as these:

a) Frequency dependence is one of the basic influencing values of electrical properties. When all other conditions are held constant, the dielectric constant of materials either desreases or remains constant as frequency increases.

b) Temperature dependence and frequency dependence are closely related in theories of dielectric dispersion, and the nature of dispersion can be explored by varying either of these factors.

c) Moisture content greatly influences the electrical properties of hygroscopic materials. The way in which water is held in a substance has an important influence on the degree of dependence of electrical properties on moisture constant. Chemically bound water exerts less influence on the dielectric properties of the material than does free water in which the polar molecules can orient freely with an applied electric field.

NOTE 4-4: Such a meter should be usable for almost all other kinds of fruit trees as well as for nut-producing trees.

d) Density of a material also influences its electrical properties.

e) Any anisotropic nature in the strucure of materials is also another factor which must be taken into account.

Our review of the literature has suggested that there has been little research done on the electrical properties of plants and trees. However, our review did not seriously consider any biochemical studies relating to electrolytic conductivity in plant materials. More specifically, we have attempted to identify some research areas that could give us a background to our potential use of a dielectric property as the basis of our development of a vitality meter.

With respect to these reported research efforts, it is well to point out that they began as early as 1943. For example, BURR (240-243) attempted to correlate seed viability, seedling vigor and plant growth (corn and cotton, and maple trees) by measuring potential differences (in the range of 0 to 50 mV) at different points on the seed and plant. WHEATON (244) has recently reviewed this work of Burr and his associates, as well as that of other researchers, on the measurement of biopotentials in plants. KHVEDELIDZE (245) made an early review of the Russian literature on the biopotentials of biological materials and gave the conclusions that the bioelectric potentials are closely related to the life processes occurring in plants and that the potentials may change in magnitude, sign and periodicity.

ASHER (246) reported on the correlation of electrical potentials with the presence or absence of female flower buds prior to their emergence in slash pine. His study also reports on the relationship of the geographical distribution of the same species to electrical potentials. MOLITORISZ (247) has studied and discussed the possible application of measurements of the natural potentials in citrus trees. His studies also included the application of d-c potentials to portions of the trees; e.g., the application of a 1.6 ma current for a 28-day period to accelerate branch growth. LAWRENCE (248,249) has reported, after using polygraphic techniques, that plants have "emotion-like" responses. His work has revealed that many of the same environmental factors and stimulations that affect animals also affect plants.

BROADHURST (250,251) using a frequency range between 100 kHz and 4.2 GHz, showed that the dielectric properties of the leaves of eight different plant species had a consistent variation with frequency. MAMULASHVILI (252) has recently compared the electrical activity in the roots and stems of plants. Instruments have been designed also to measure electrical impedances of plants which can be correlated with the health condition of the plant (253) and with the winter hardiness of plants (254,255). LaPOINT and VAN CLEVE (256) have developed a low-cost, sensitive, battery-operated recording dendograph system for use in measuring tree diameter growth, temperature and other environmental parameters.

240) BURR, H. S., "Electrical Correlates of Pure and Hybrid Strains of Sweet Corn", Proceedings National Academy of Science 29(6): 163-166 (1943).

241) BURR, H. S., "Tree Potentials", Yale J. Biol. Med. 19(3): 311-318 (1947).

242) BURR, H. S., "Diurnal Potentials in the Maple Tree", Yale J. Biol. Med. 17(6): 727-734 (1945).

243) BURR, H. S., "An Electrometric Study of Cotton Seeds", J. Exp. Zoo. 113(1): 201-210 (1950).

244) WHEATON, F. W., "Influence of Electrical Energy on Plants. A Review", Maryland Agr. Exp. Sta., Dept. Agr. Eng., Univ. of Maryland, College Park, Contribution No. 4262, 1970.

245) KHVEDELIDZE, A., "On the Question of Bioelectrical Potentials in Plants", Advances in Contemporary Biology, USSR, 46 1(4): 33-47 (1958).

246) ASHER, W. C., "Electrical Potentials Related to Reproduction and Vigor in Slash Pine", For. Sci. 10(1): 116-124 (1964).

247) MOLITORISZ, J., "Engineering Applications of Electrophysiological Properties of Plants", Agr. Sci. Rev. 4(3): 8-11 (1966).

248) LAWRENCE, L. G., "Electronics and the Living Plant", Electronics World 82(4): 25-28 (1969).

249) LAWRENCE, L. G., "More Experiments in Electroculture", Popular Electronics, p 63-68, 93 (1971).

250) BROADHURST, M. G., "The Dielectric Properties of Leaves, Sticks and Dirt at Radio and Microwave Frequencies", p 146-152 in 1968 Ann. Report Conf. on Electrical Insulation and Dielectric Phenomena, Natl. Acad. Sci. Pub. 1705 (1969).

251) BROADHURST, M. G., "Complex Dielectric Constant and Dissipation Factor of Foliage", Natl. Bur. Stds. Report 9592, U.S. Dept. of Commerce 1970.

252) MAMULASHVILI, G. G., et al, "Comparative Study of Electrical Activity of the Root and Stem of Plants", Sov. Plant Physiol. 19(3): 462-467 (1972).

253) de PLATER, C. V. and Greenham, C. G., "A Wide-range AC Bridge for Determining Injury and Death", Plant Physiology 34(6): 661-667 (1959).

254) WILNER, J., et al, "Note on Two Electrolytic Methods for Determining Frost Hardiness of Fruit Trees", Can. J. Plant Sci. 40: 563-565 (1960).

255) BRACH, E. J. and Mason, W. J., "A Stable Multi-vibration for Measurement Impedance of Plant Leaves and Stems", Can. J. Bot. 43: 995-997 (1965).

256) LaPOINT, G. and Van Cleve, K., " A Portable Electronic Multichannel Dendograph and Environmental Factor Recording System", Can. J. For. Res. 1: 273-277 (1971).

4.2.2.1 Technical Approach: This work to develop a sensor that could detect the lack of vitality (or viability) is based on the use of electrical impedance measurements. The concept was conceived because equipment existed and the research group had considerable expertise in the use of electrical impedance measurements. The studies included both laboratory and field tests.

The basic technique is to measure the electrical impedance or conductance (Z) of peach tree wood. The GR Impedance Bridge used gave the result of the Z measurement in terms of resistance (R) and a dissipation factor (D) of the unknown impedance. The Q of an electrical circuit (NOTE 4-5) involving resistance and reactance is

$$Q = \frac{\omega L}{R} \text{ for inductive reactance}$$

or

$$Q = \frac{1}{\omega CR} \text{ for capacitive reactance}$$

NOTE 4-5: Q is sometimes called the 'quality factor' and is the ratio of the resistance which is, in fact, the ratio of the energy stored to the energy lost per unit time (μ per cycle for AC circuits).

where $\omega = 2\pi F$. Q is also the tangent of the phase angle of the impedance; (Z) is the sum of R and ωL or ωC vectors. D, obtained from the bridge, is the cotangent of the phase angle, or

$$d = \frac{1}{Q}$$

Thus, the bridge readout can be obtained in polar form

$$Z < \Phi$$

or rectangular form

$$Z = R \pm JXi$$

where, + JX indicates inductive reactance and - JX a capacitive reactance. Similar measurements can be made with a Q meter.

4.2.2.2 <u>Laboratory Tests</u>: This principle was first used in laboratory tests on segments of live dogwood and peach tree wood (trunk, scaffold or branch tissue). After impedance measurements were made on the live specimens, each specimen was "killed" by freezing in liquid nitrogen or by refrigeration for long periods of time and its impedance measured. FIGURES 4.2/1, 4.2/2, 4.2/3 and 4.2/4 compare some of these tests.

The observed D Values are strongly significant when the two types of wood are compared. The following observations are of interest based on the data shown in each FIGURE.

1. The tests were performed in such a manner as to measure the impedance of the wood in its healthy state and then repeat the impedance measurements after it was "killed". Significant changes in impedance occurred.

2. The average D value of the healthy wood is 6.78 as contrasted with 17.4 the average D value for the "short-life" or "killed" wood.

3. The average C value for all of the healthy wood samples is 1.72 as contrasted with an average of 0.818 for all the "short-life" or "killed" wood.

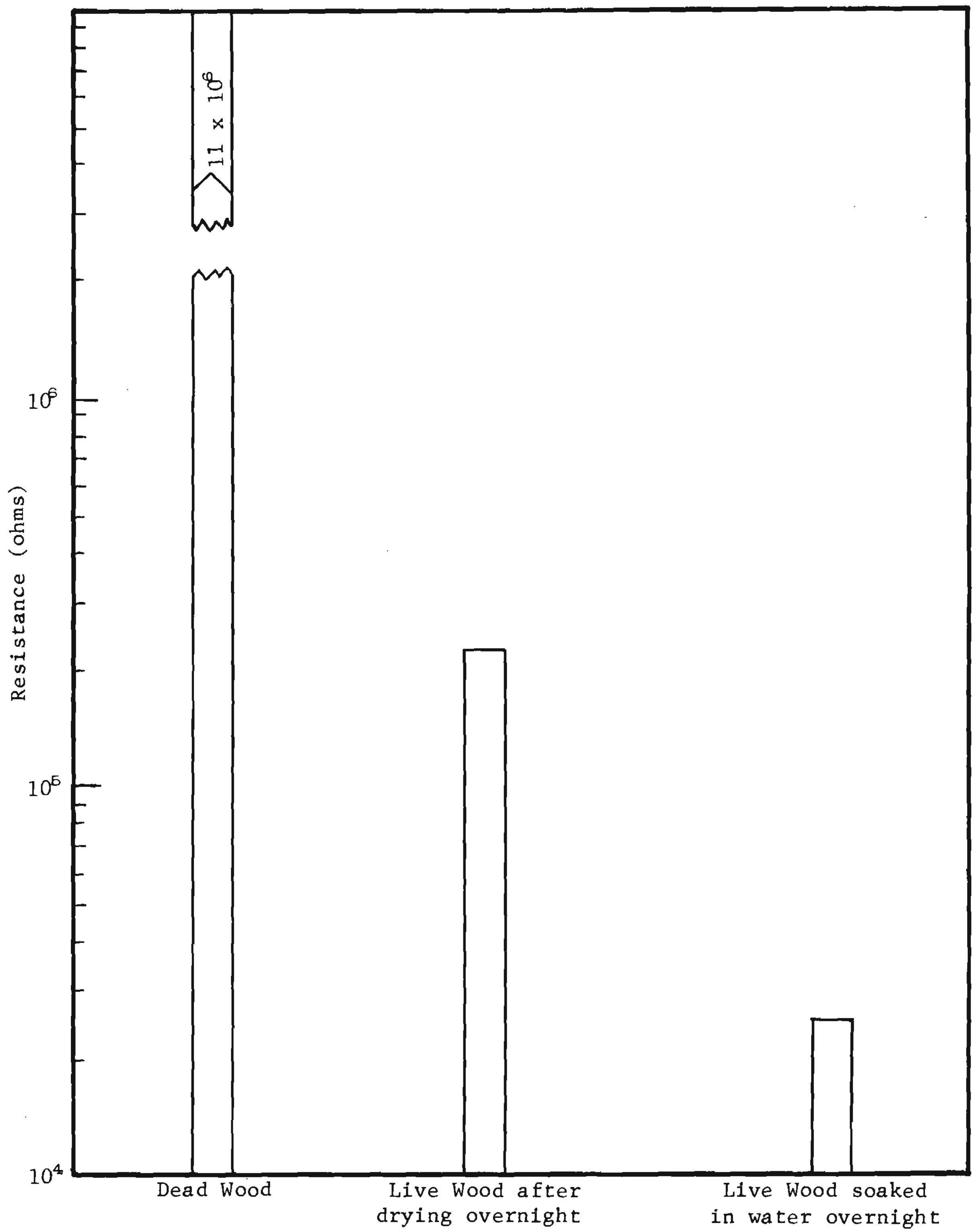


FIGURE 4.2/1 MEASUREMENTS OF DOGWOOD BRANCHES WHICH EXHIBIT PURE RESISTANCE (i.e. THE IMPEDANCE HAS NO CAPACITIVE COMPONENT)

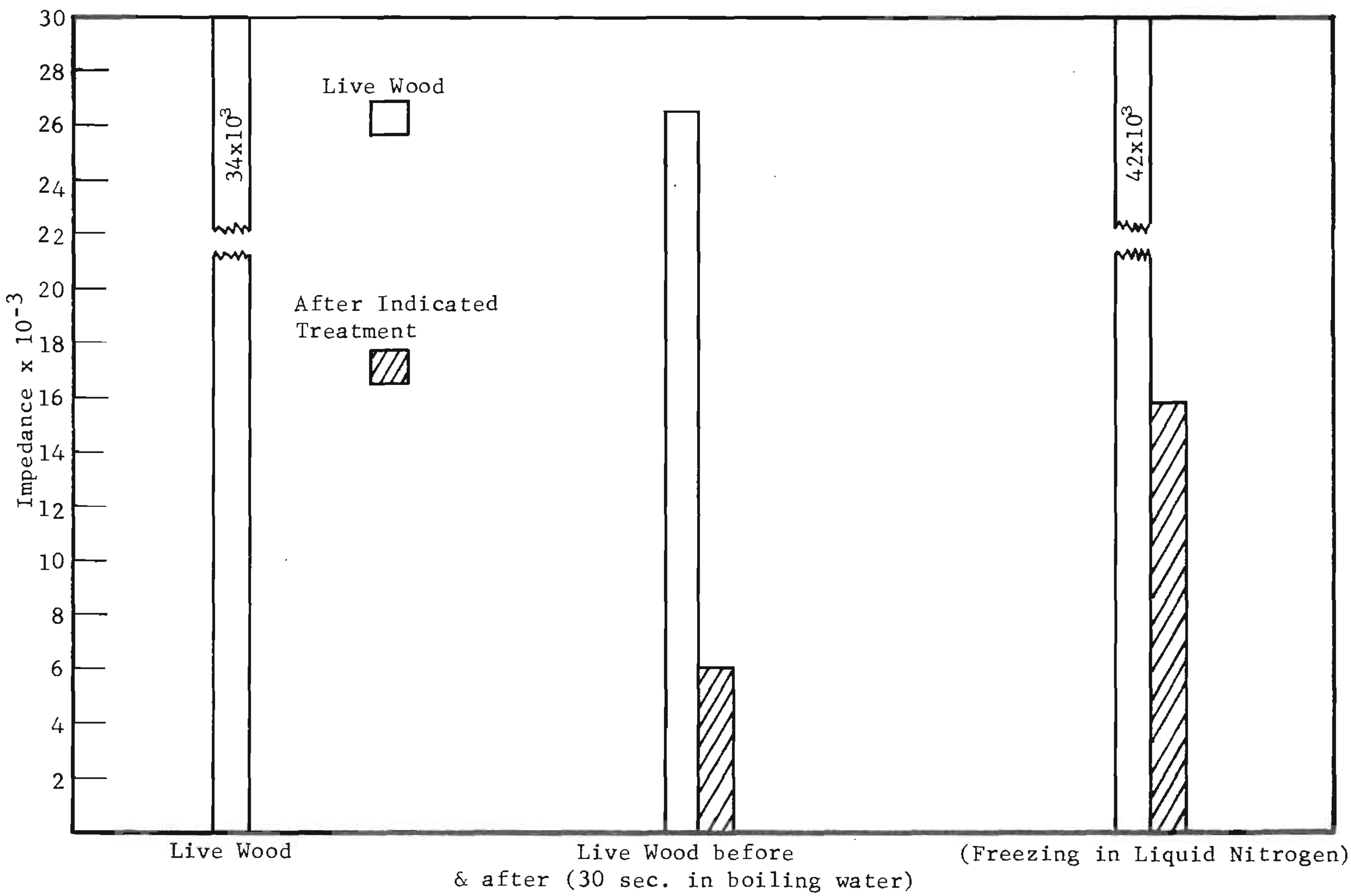


FIGURE 4.2/2 ELECTRICAL IMPEDANCE OF DOGWOOD BRANCHES MEASURED AT 1 kH_z

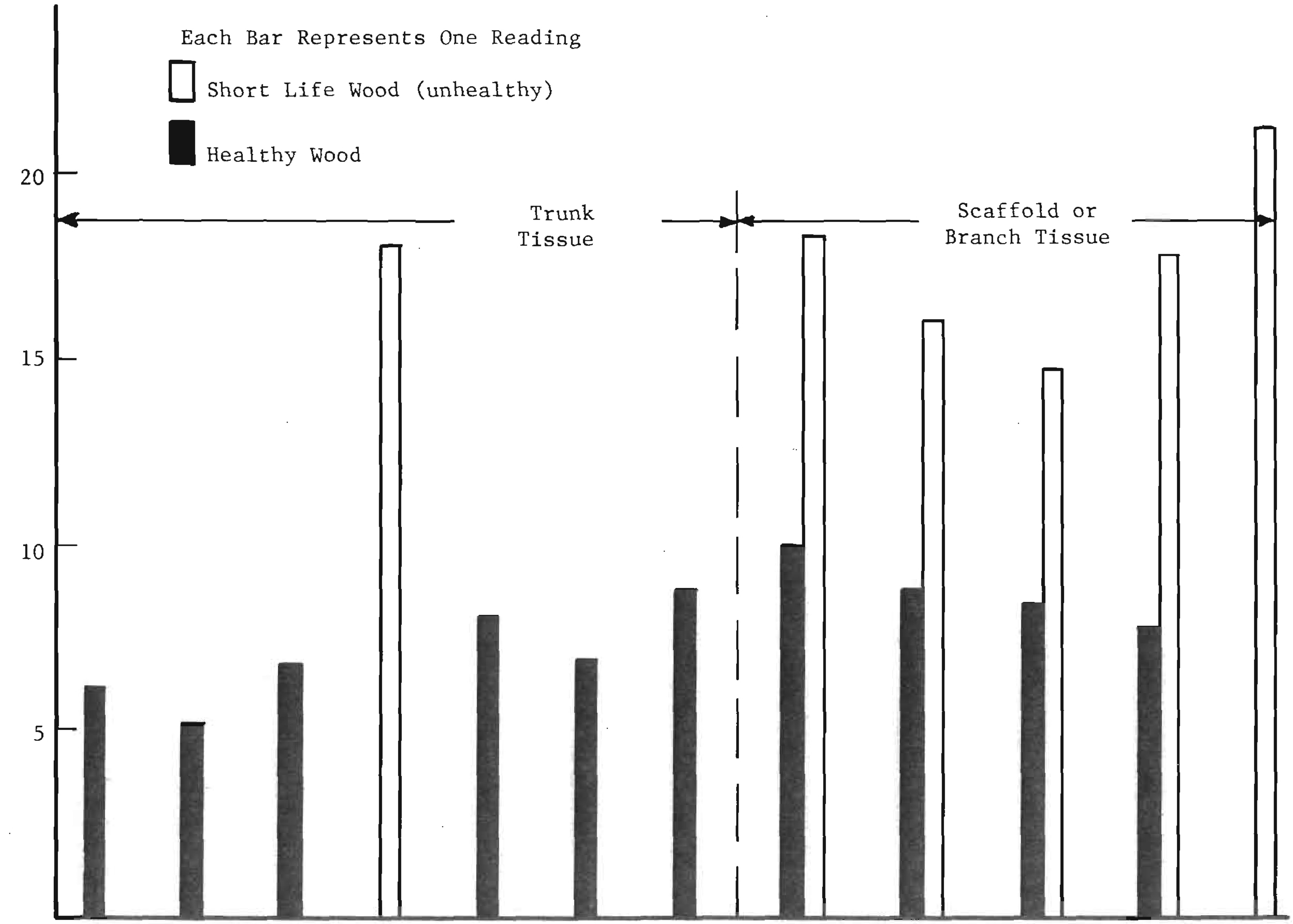


FIGURE 4.2/3 COMPARISON OF D VALUES OF PEACH WOOD SAMPLES FROM BYRON, GEORGIA

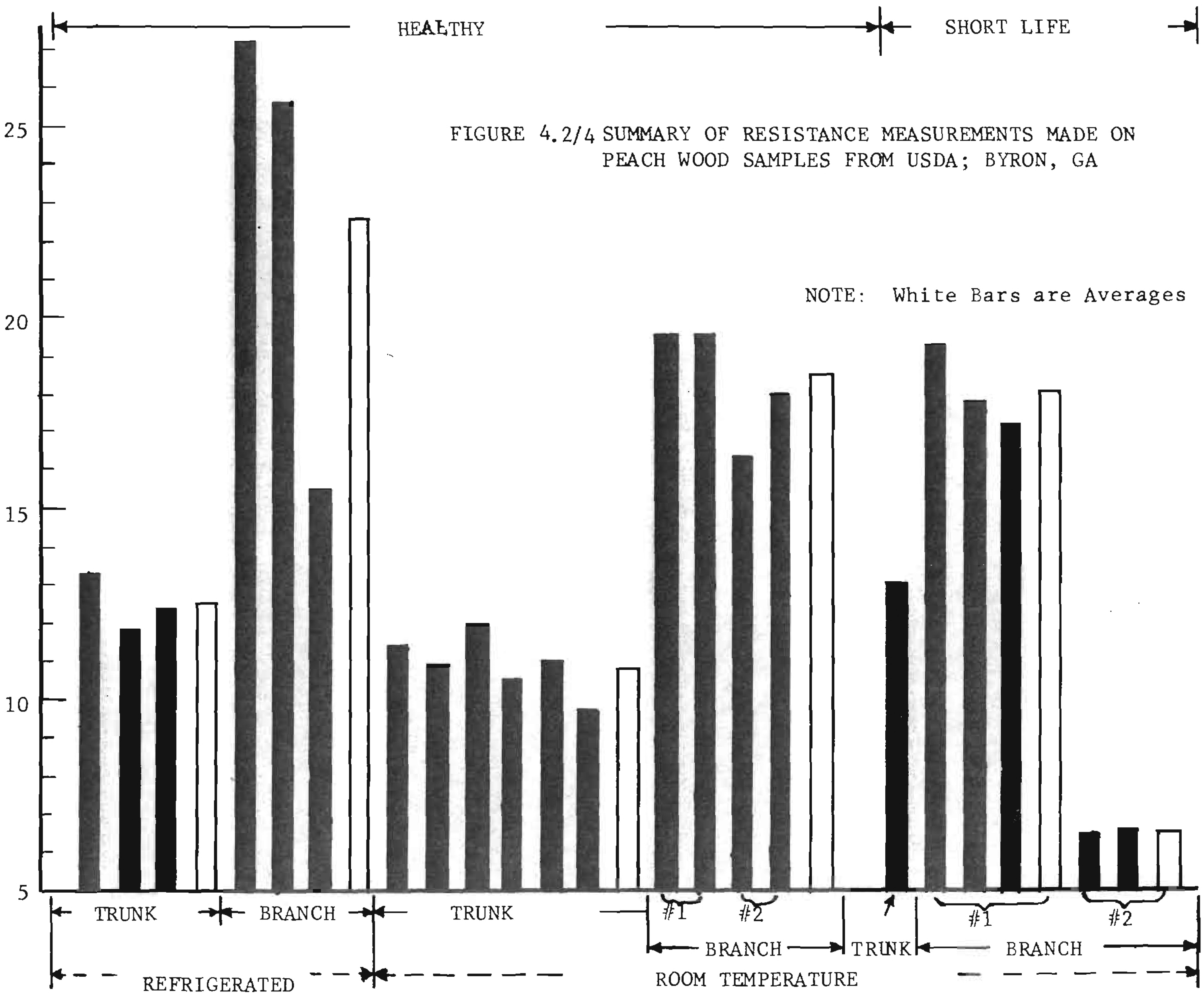


FIGURE 4.2/4 SUMMARY OF RESISTANCE MEASUREMENTS MADE ON PEACH WOOD SAMPLES FROM USDA; BYRON, GA

From this approach, a series of field tests were designed to test the premise that the electrical equivalent of peach wood is

$$R = \frac{1}{c}$$

and that, by controlling the area of the electrodes on standing trees, the dielectric constant of the total tree could be obtained.

4.2.2.3 Field Tests: Our basic techniques of field experimentation involved the placement of gold-plated electrodes (probes) into the cambium layers at points on the tree trunk or in the scaffold (on branching) area of the tree. FIGURE 4.2/5 is a schematic of the probe locations and instrumentation used in these field tests.

At the time of measurements, the air temperature was recorded; also, most measurements were made in a favorable weather cycle. Our initial experiments were designed to

a) Compare the use of horizontal and vertical probe locations,
b) Compare impedance measurements obtained by use of different kinds of metal probes,
c) Compare the placement of the probes at/or near the base or at higher positions on the trunk,
d) Use of an elapsed time period, after locating probes on the tree, before taking impedance measurements,
e) Study the effects that diurnal conditions might have on the measurements, and
f) Test utility of making a single measurement at any time during a test period.

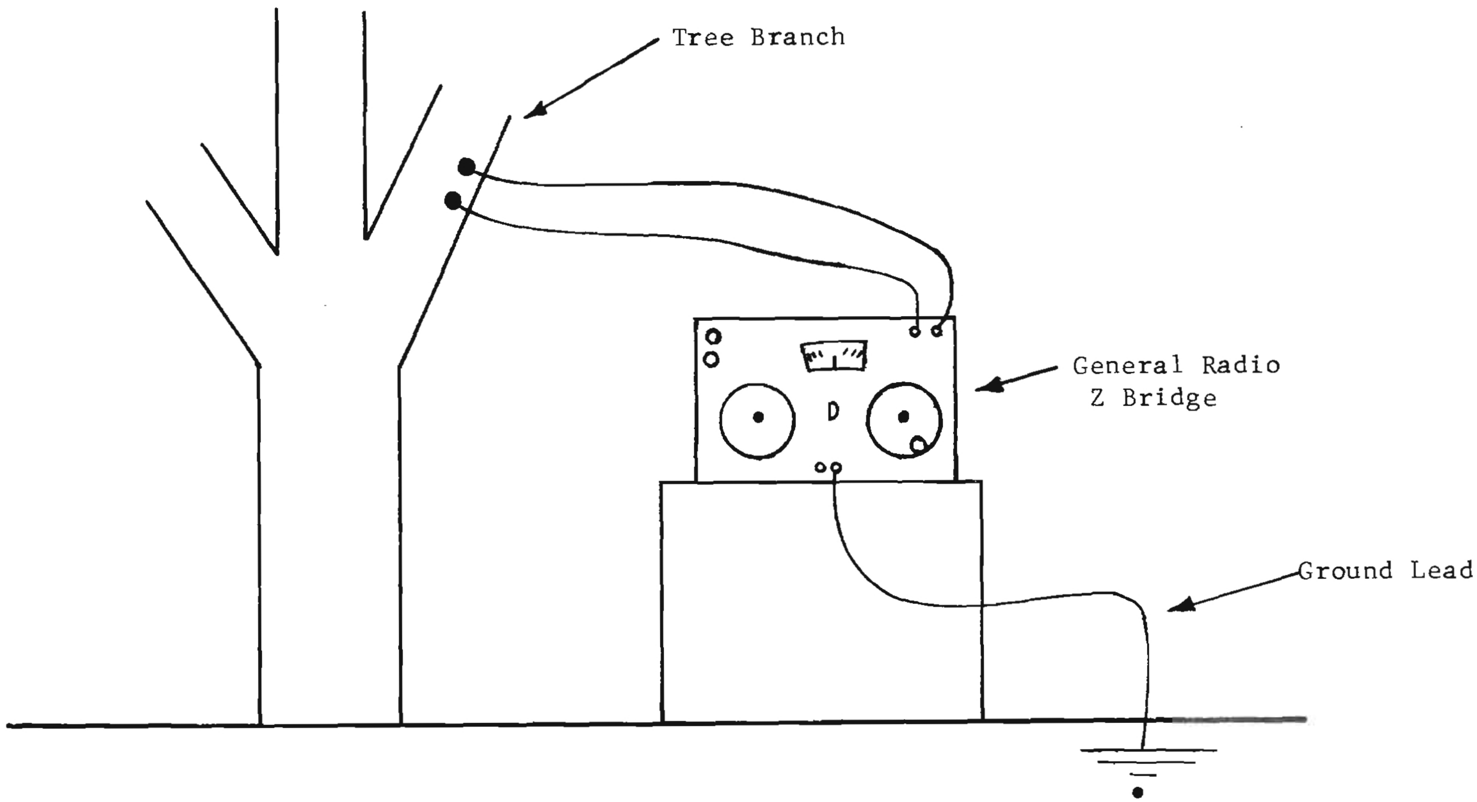


FIGURE 4.2/5 ARRANGEMENT OF VITALITY METER ON TREE

The results of these experiments can be described in this manner:

a) FIGURES 4.2/6 and 4.2/7 show results observed in tests of probes held in horizontal and vertical positions on a single peach tree for at least 27 hours. Some speculation exists that (1) early biological damage could have resulted to the cambium cells at the point of probe contact and that (2) the temperature at the time of measurement might influence the observed data. Apparently, electrode position has very little influence on the measurements; however, in an extensive "ground-truth" survey of an orchard, the analyst must use the same probe orientation on each tree being measured.

b) FIGURE 4.2/8 shows data obtained from a series of experiments in which the measurements obtained in the use of nickel and stainless steel probes were compared with these from gold probes. All later experiments were carried out with the use of gold-plated steel probes.

c) FIGURES 4.2/9 and 4.2/10 compares the placement of the probes on the tree trunk at different distances from the ground. Evidence again exists for apparent recovery of the cambium layer after the probe has been inserted. There is also some evidence that there is either an effect on impedance measurements by reason of probe location or the probe location is influenced by temperature.

d) FIGURE 4.2/11 shows data recorded for a span of approximately 7 hours in which impedance measurements were made on individual trees (flowering peach, fruiting peach and white oak) after the probes had been inserted and the cambium layer allowed to recover for at least 10 minutes before the measurements were made. These observations suggested that it was practical to wait for some time interval before beginning a measurement. These data also suggest that there is a temperature influence; hence, either a single impedance measurement or a series of readings (3 or 4) over a short period of time would be adequate.

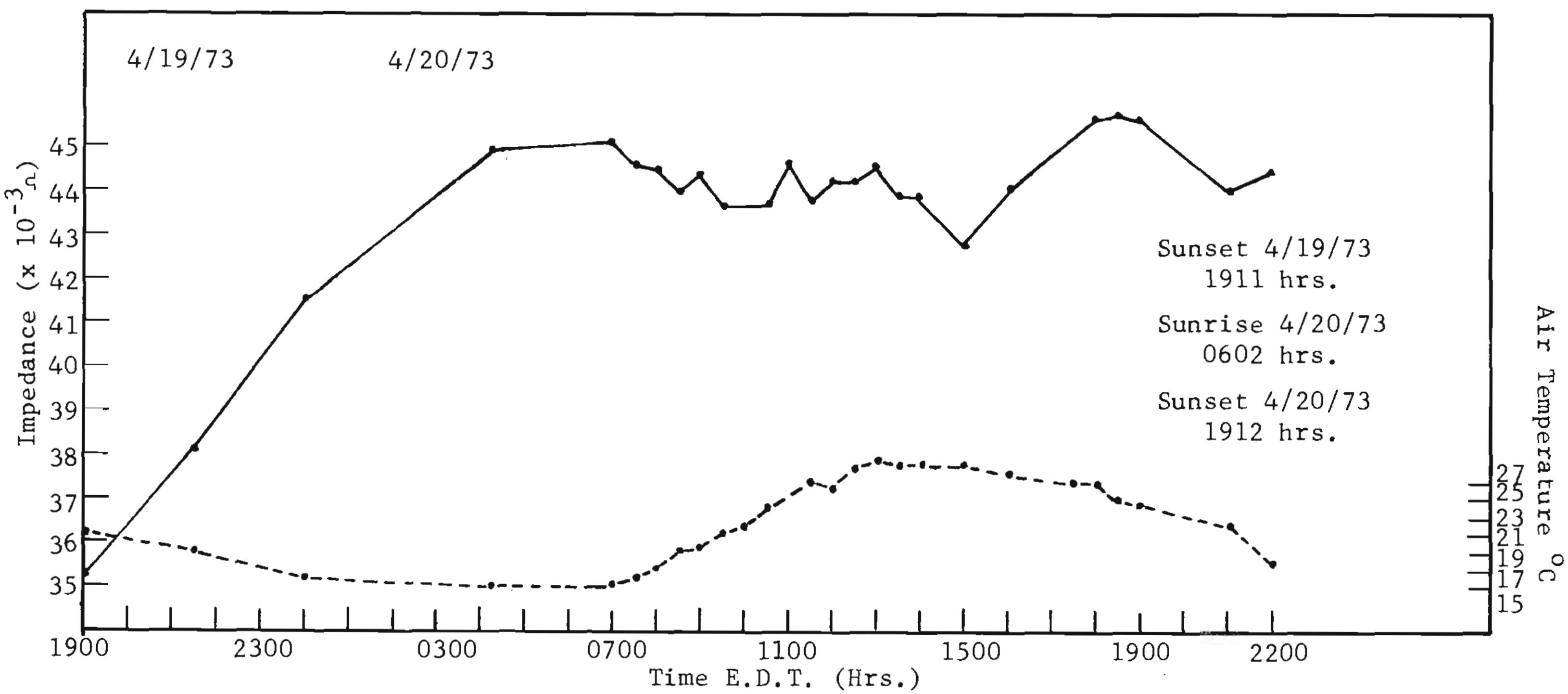


FIGURE 4.2/6 PROBES HORIZONTAL

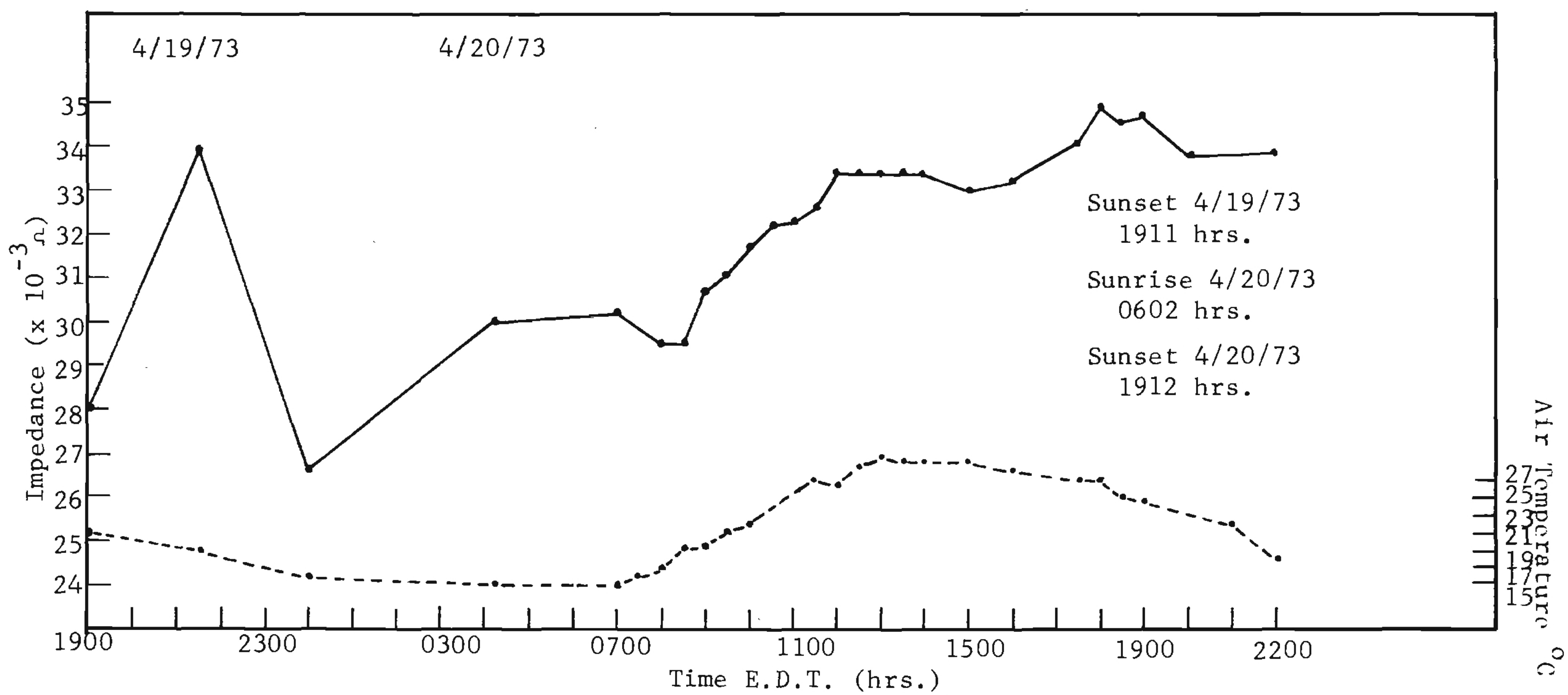


FIGURE 4.2/7 PROBES VERTICAL

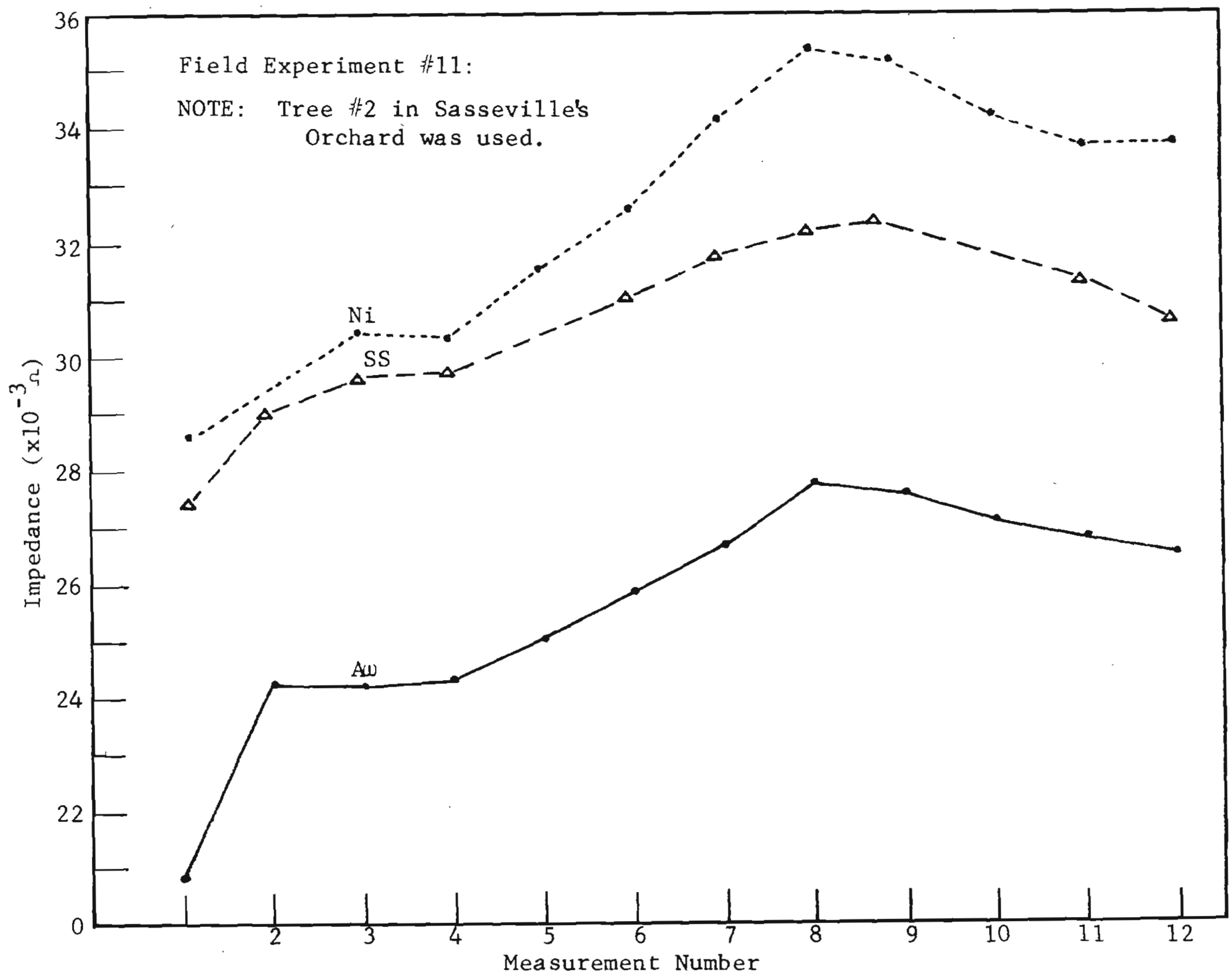


FIGURE 4.2/8 COMPARISON OF DIFFERENT METAL PROBES

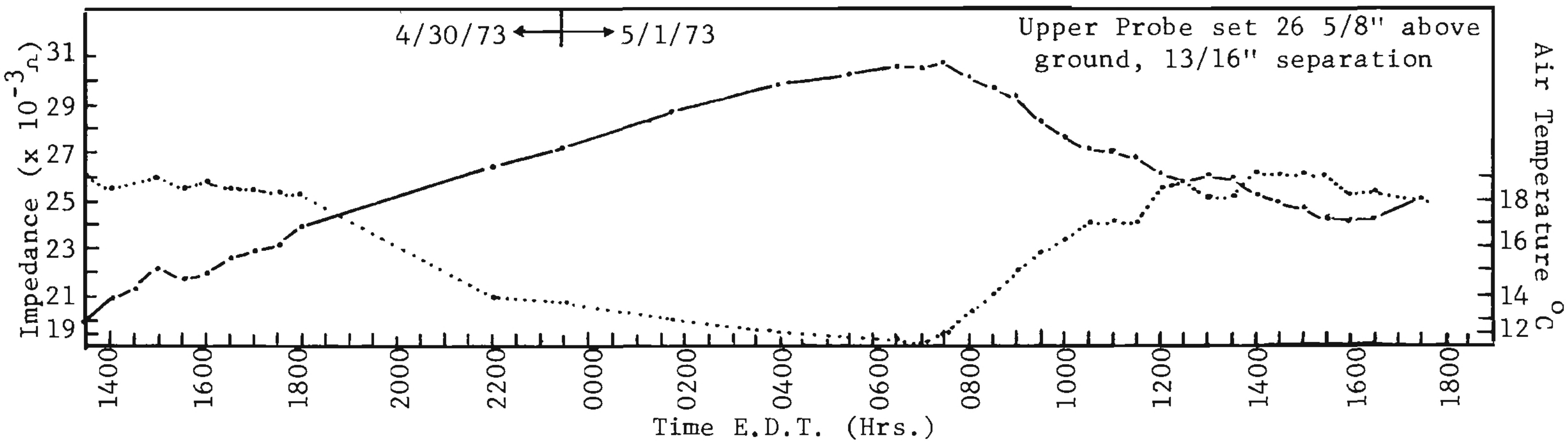


FIGURE 4.2/9 DIURNAL VARIATIONS IN IMPEDANCE OF LIVING PEACH WOOD MEASURED WITH STEEL PROBES INSERTED IN TRUNK

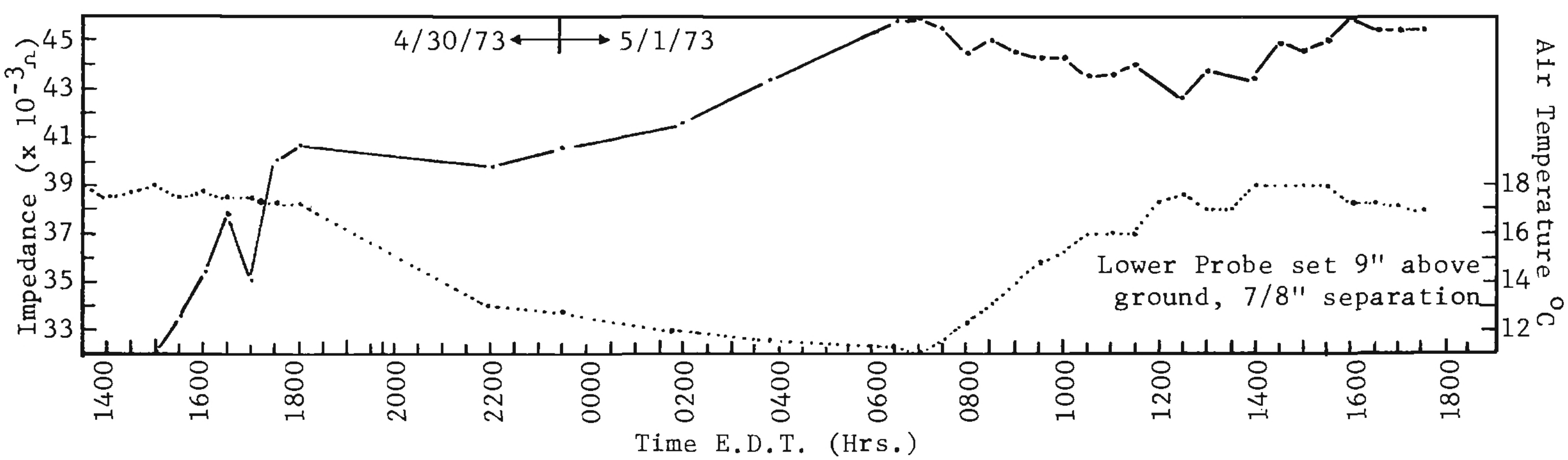


FIGURE 4.2/10 DIURNAL VARIATIONS IN IMPEDANCE OF LIVING PEACH WOOD MEASURED WITH STEEL PROBES INSERTED IN TRUNK

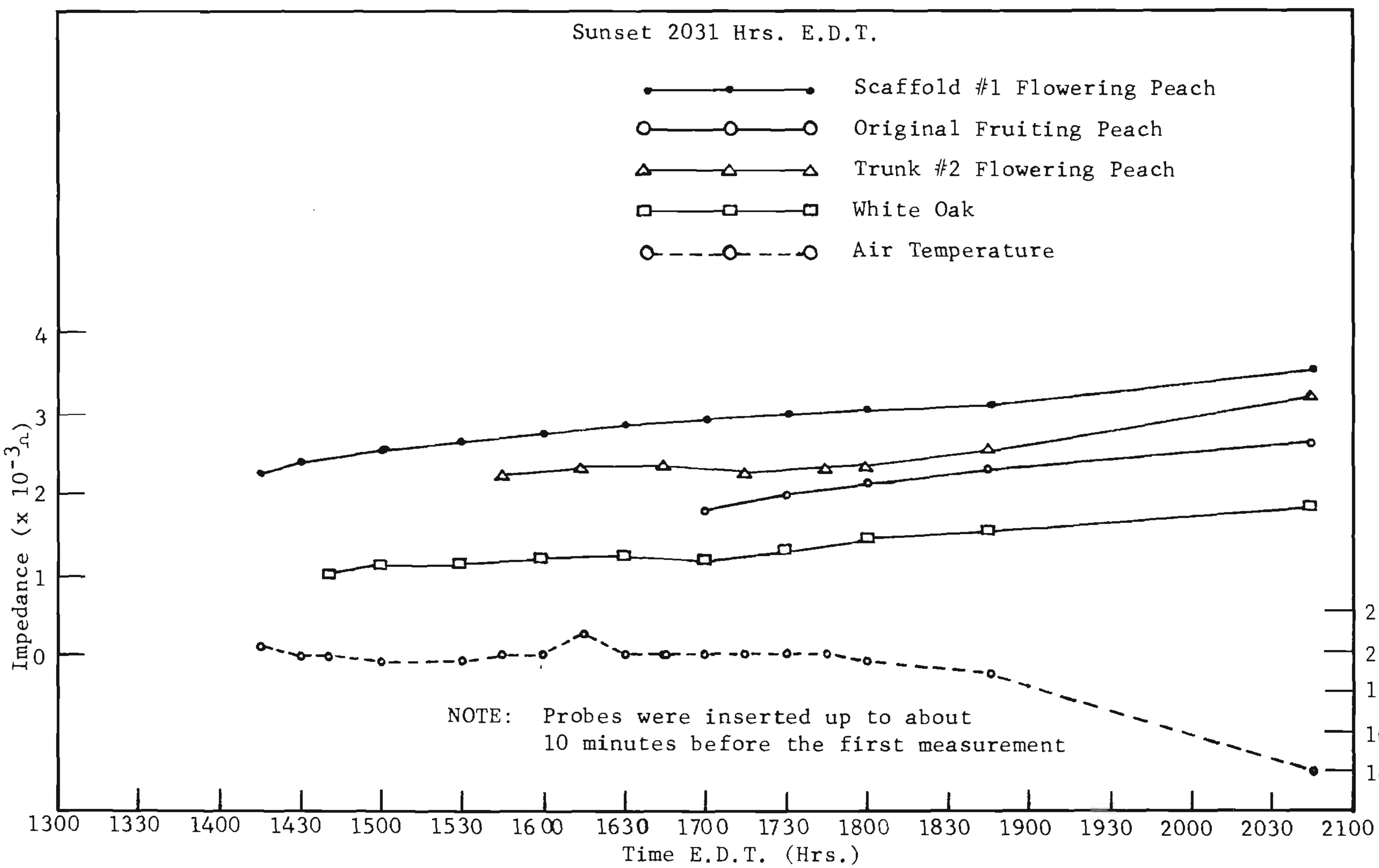


FIGURE 4.2/11 PROBES INSERTED IN TRUNK OR BRANCH

e) FIGURES 4.2/12 and 4.2/13 show data observed from a series of measurements made over approxiamtely 27 hours on a pine tree and a flowering peach tree. The probes were mounted 29" from the ground in a vertical position and separated from each other at a distance of 7/8 of an inch. Tree location with respect to sun and shade at the hour of measurement are noted; however, these variations do not appear to have an influence on the measurement, except at those times when the temperature is lowering. Hence, there is further substantiation that temperature changes can influence impedance.

f) FIGURE 4.2/14 records the data taken at approximately the same time for a period of 6 days. The probes were kept in the same location on each tree species and, at the time of measurement, they were connected to the meter. These "single-print" measurements show a consistency in data (except for the white oak tree). However, the attachment of the meter leads to the probe could have caused a distortion in probe location so that some of the data reflect significant differences. The use of longer length probes and the setting of each probe more firmly within the trunk merits consideration.

Two very interesting situations were observed during this test period. During the fourth night and most of the next day it rained and the trunks of the trees became very wet. On the fifth night, a nearby electrical storm produced momentary effects upon the bridge null meters while the bridge was attached to a tree. Hence, there is some reason to believe that the data of FIGURE 4.2/14 reflects these conditions.

These field tests were extended to include surveys of orchard sites - 2 areas at the USDA Fruit and Nut Tree Research Station, Byron, Georgia, and an abandoned orchard (SASSEVILLE'S) at Fairburn, Georgia. In the USDA orchards, 18 trees from one orchard (labeled Area #1) and 8 trees in the second orchard (Area #2) were measured. FIGURES 4.2/15 and 4.2/16 show data taken and categorization of tree groupings just after the probes have been placed in the trees. FIGURE 4.2/17 is a compilation of these observations. FIGURE 4.2/18 is a compilation of the observed measurements on the same groups of trees after the probe had been held in position for a period of from 2 to 3 hours.

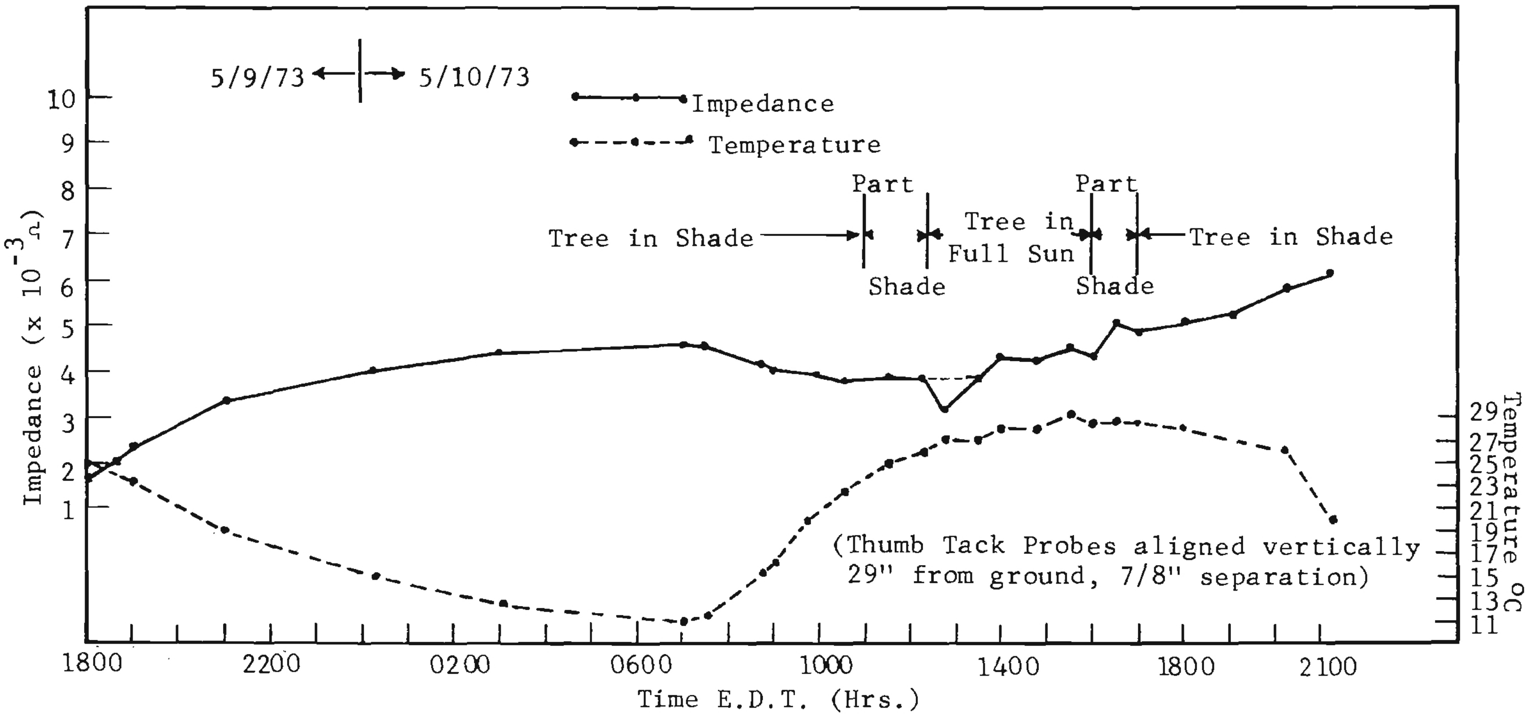


FIGURE 4.2/12 DIURNAL VARIATIONS IN IMPEDANCE OF LIVING PINE TREE WOOD MEASURED WITH STEEL PROBES INSERTED IN TRUNK

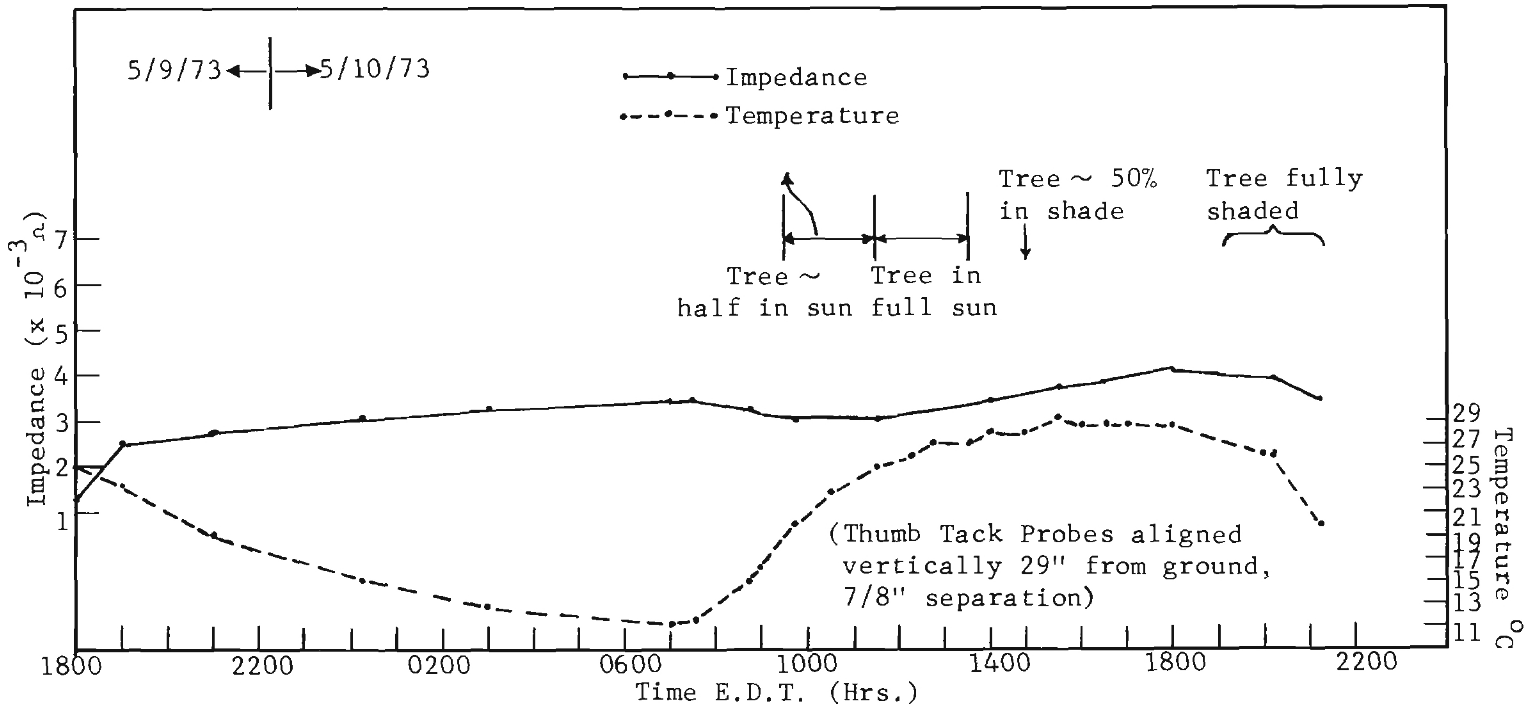


FIGURE 4.2/13 DIURNAL VARIATIONS IN IMPEDANCE OF LIVING PEACH* WOOD MEASURED WITH STEEL PROBES INSERTED IN TRUNK

*Flowering Peach Tree as Opposed to Fruiting Tree Measured Previously

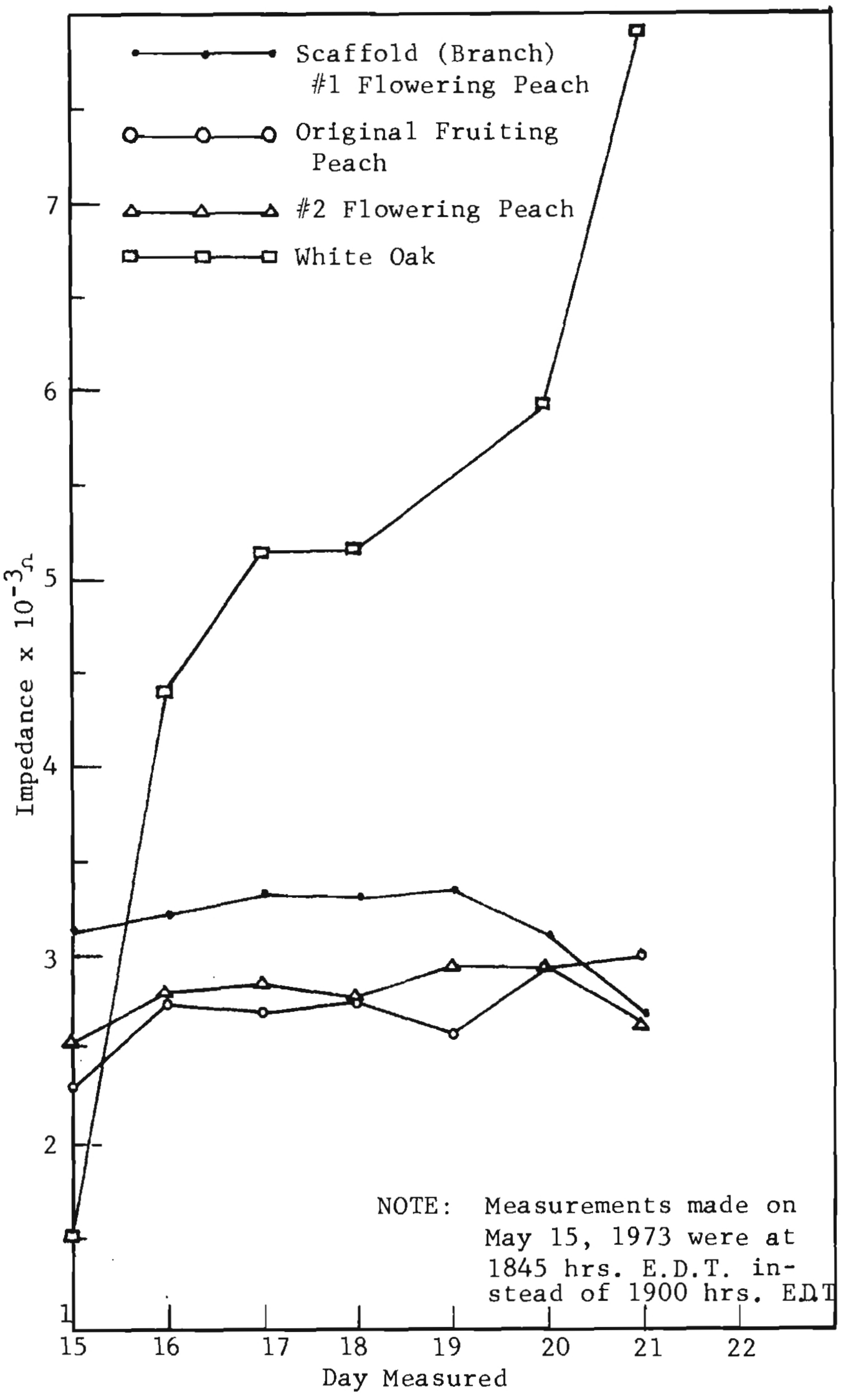


FIGURE 4.2/14 IMPEDANCES MEASURED AT 1900 HRS. E.D.T. DAILY MAY 1973

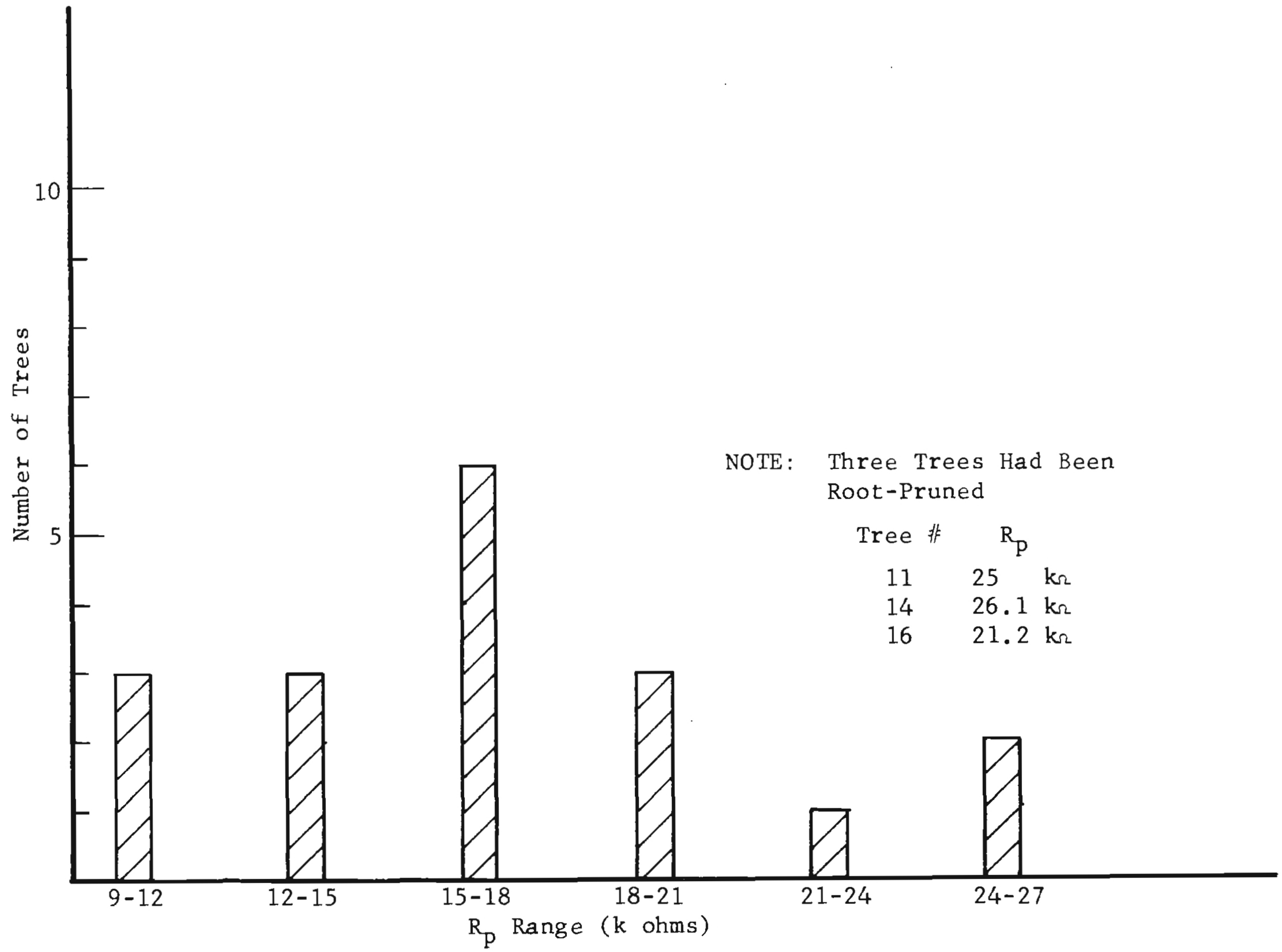


FIGURE 4.2/15 R_p MEASUREMENTS AT USDA; BYRON, GA
(1st Series—Just After Probe Placement)
Area #1 Only

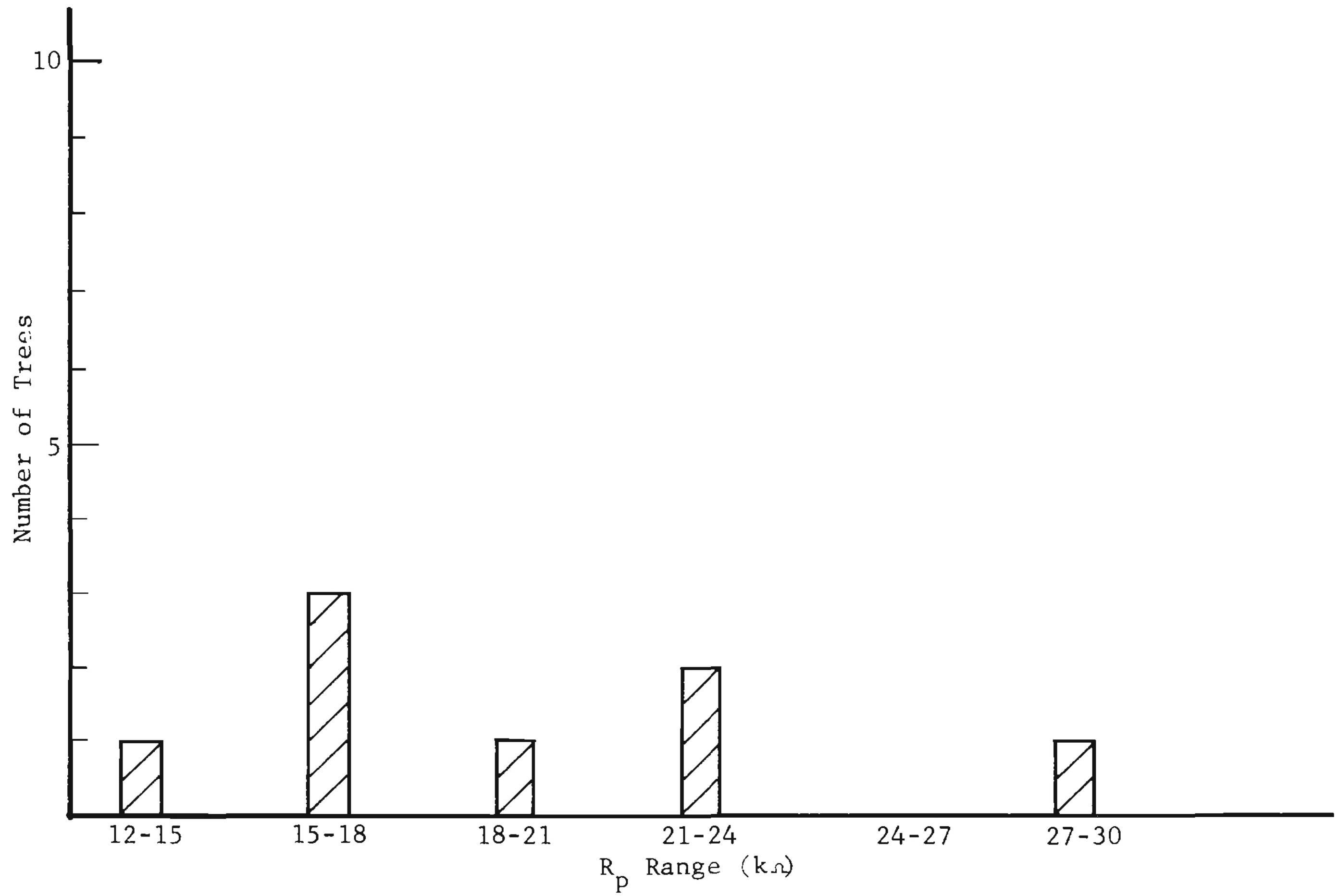


FIGURE 4.2/16 R_p MEASUREMENTS AT USDA; BYRON, GA
(1st Series—Just After Probe Placement)
Area #2 Only

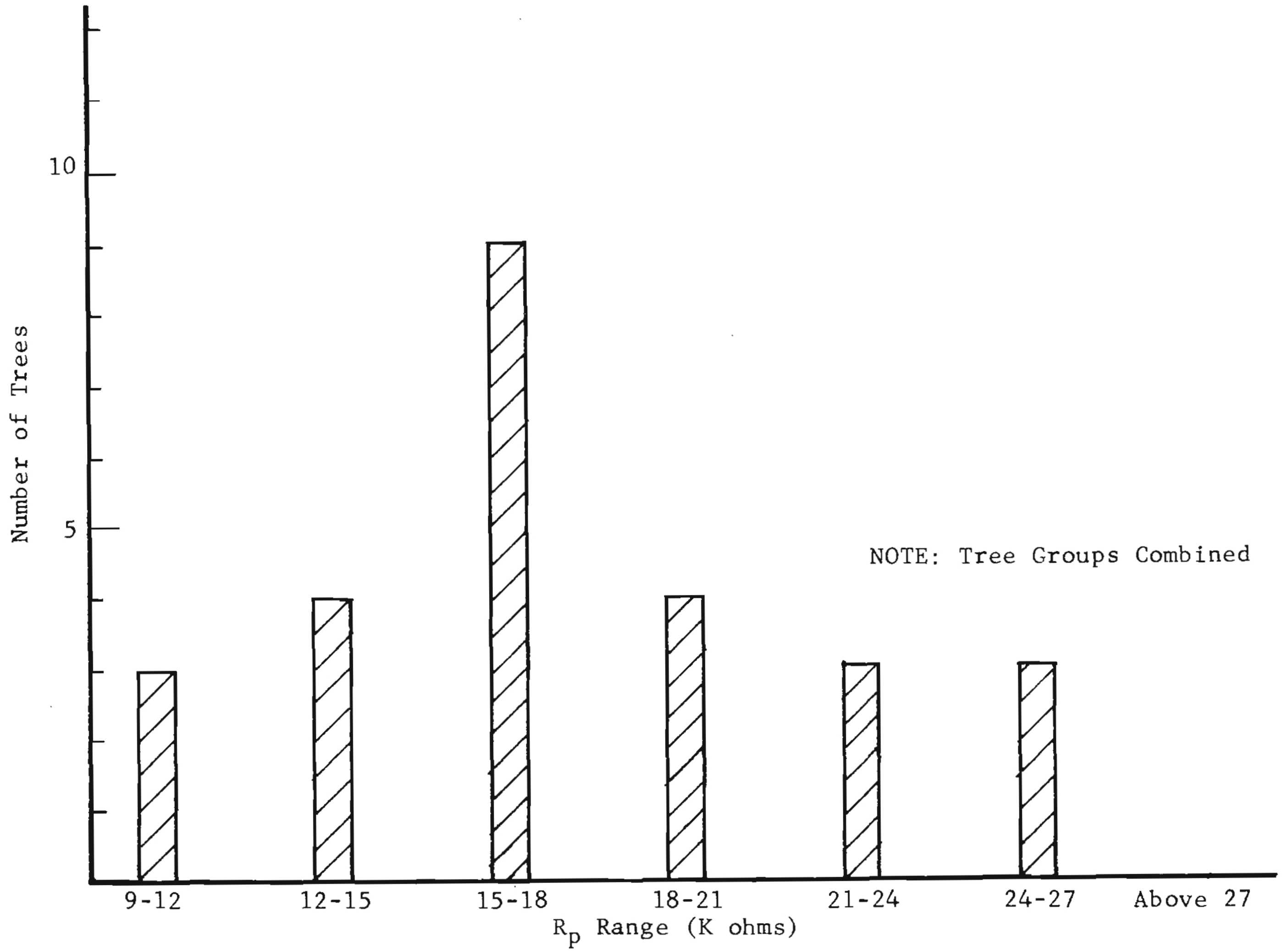
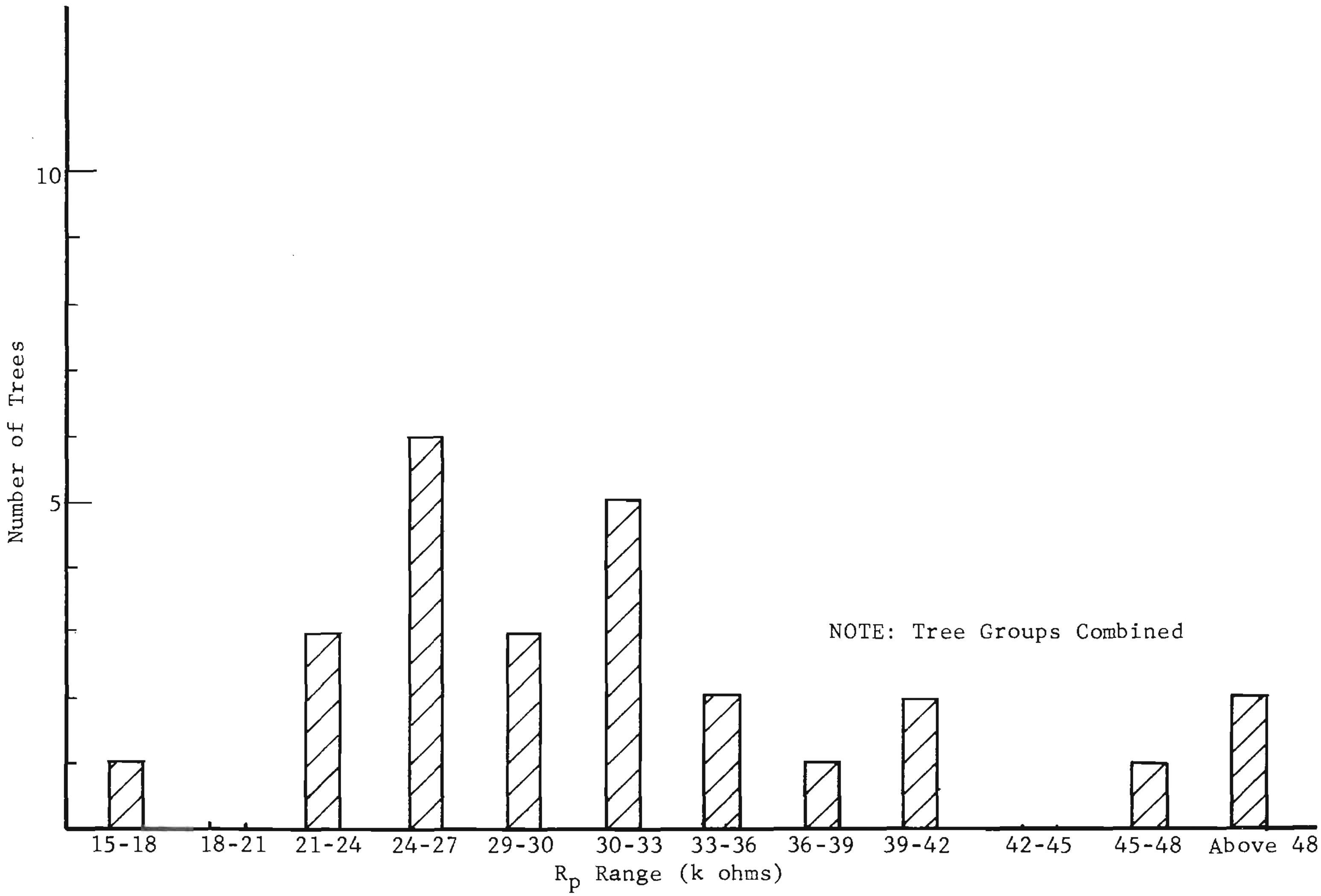


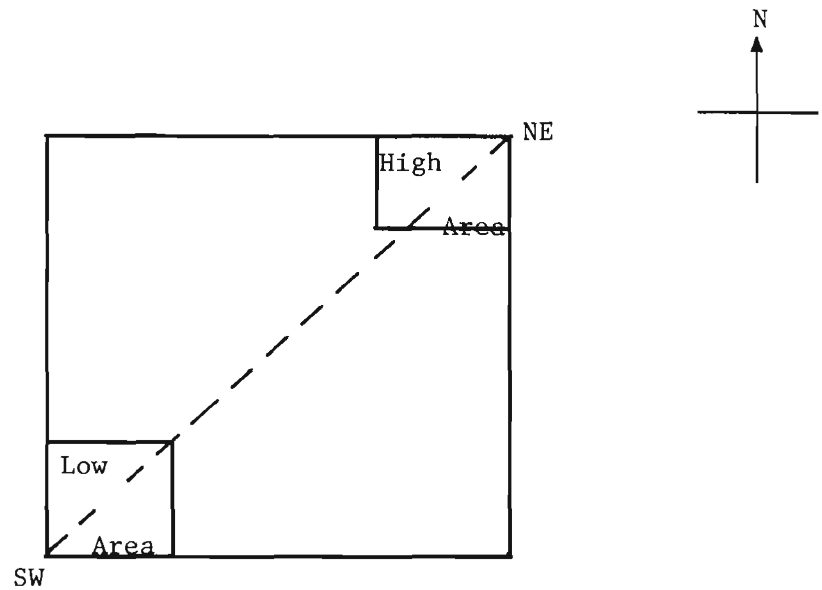
FIGURE 4.2/17 R_p MEASUREMENTS USDA, BYRON, GA
(1st measurement—immediately after probe placement)



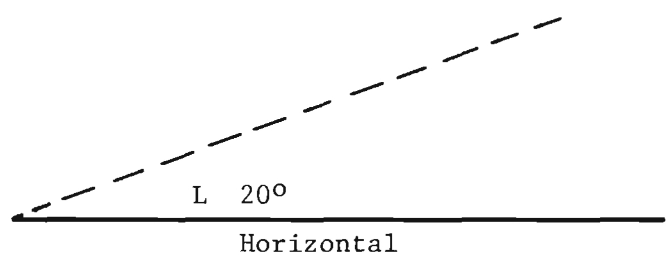
<u>FIGURE 4.2/18</u>

R_p MEASUREMENTS ON PEACH TREES AT THE USDA FRUIT AND NUT RESEARCH STATION; BYRON, GA

(Measurements after Stabilization Period 2-3 hrs.)



TOP VIEW
Showing Locations of Areas Tested



SIDE VIEW
Showing Approximate Slope of Soil Surface Along
a Diagonal Line From Southwest to Northeast

FIGURE 4.2/19 E.M. SASSEVILLE's ORCHARD
(near Fairburn, GA)

Approximately 80 Peachtree Remaining From Original 1500 Planted in 1962.
Trees Under Care Up to 1972 When Fertilization Was Discontinued.

The SASSVILLE Orchard (near Fairburn, Georgia) is an abandoned orchard situated on the slope of a hill. Approximately 80 of the original 1500 trees planted in 1962 remain. 42 of these trees are located at orchard elevations we have described as being "low" and "high" (see FIGURE 4.2/19). FIGURE 4.2/20 shows data taken immediately after probe placement. FIGURE 4.2/21 is representative of the increase in impedance measurement after the probes had been stabilized (in the tree trunks) for a period of time.

FIGURE 4.2/22 compares the readings of selected trees from each section of the orchard. These data suggest that the trees in the "high" area of the orchard are less viable than those in the "low" area. In order to understand if the lack of a soil nutrient contributes to this state, soil samples taken from the base of trees #11 (high area) and #19 (low area). (NOTE: Visual observations credit tree #19 as being the healthiest tree in the orchard.) Each soil sample was analyzed by emission spectroscopy. The results of these quantitative tests are shown in Table 4-II.

TABLE 4-II

SPECTROGRAPHIC ANALYSIS OF SOILS TAKEN NEAR TREES IN THE SASSEVILLE ORCHARD

Element	Tree #11	Tree #19
Sc	VS*	VS
P	W	W
Mn	M	M
Mg	MS	M
Pb	T	T
Cr	W	W
Fe	MS	MS
Al	S	S
V	W+	W
Cu	MW	MW
Na	W+	W
Ti	M	M
Ni	W	T
K	MW	MW
Ca	W	W+

* Spectrographic line intensities = very strong (VS), strong (S), medium (M), weak (W) and trace (T), denoting possible presence of elements from trace to large amounts in the sample.

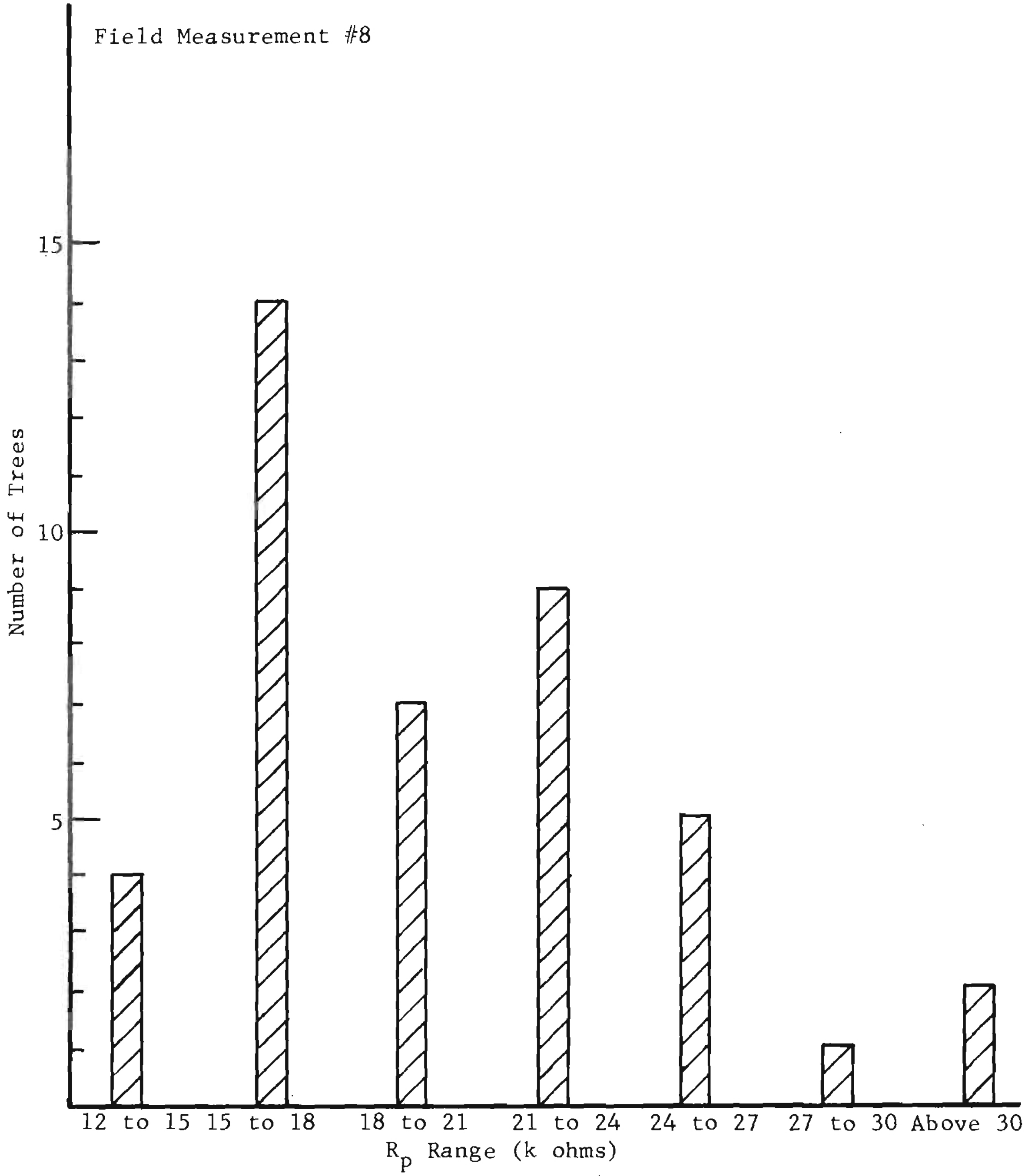


FIGURE 4.2/20 R_p MEASUREMENTS SASSEVILLES ORCHARD
(Measurement Immediately after Probe Placement)

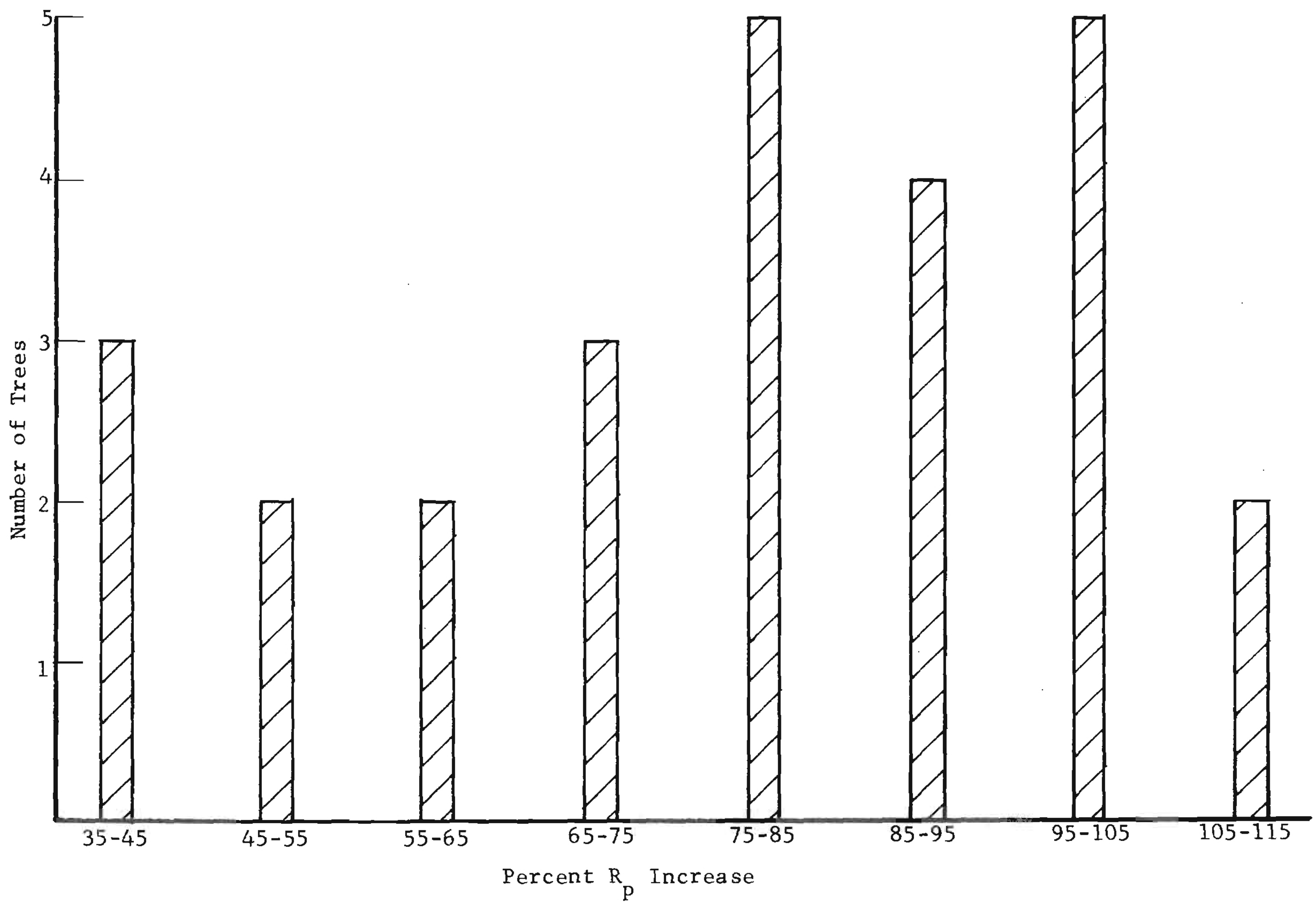


FIGURE 4.2/21 PERCENTAGE INCREASE IN R_p BETWEEN FIRST AND SECOND MEASUREMENTS BOTH AREAS

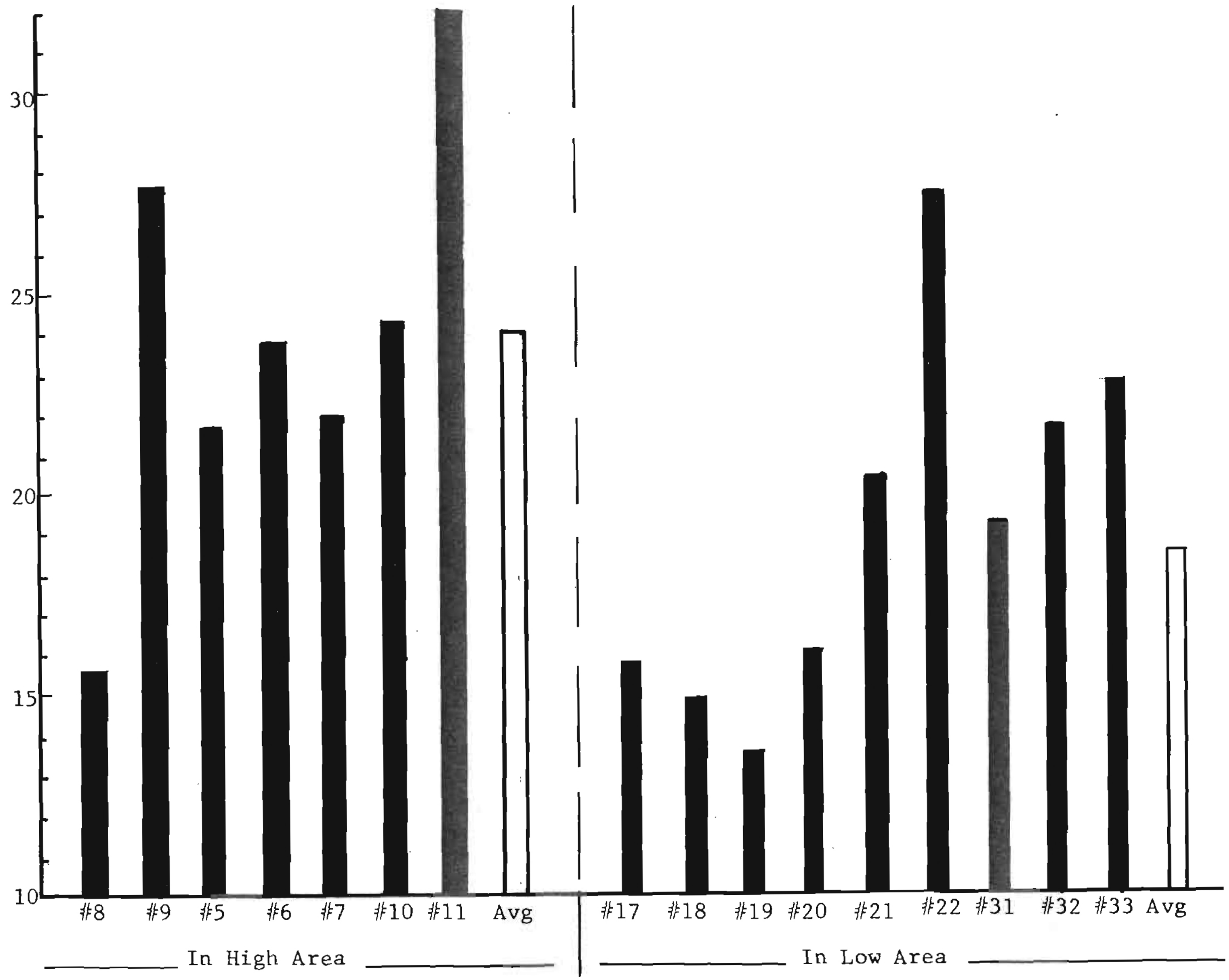


FIGURE 4.2/22 COMPARISON OF TREES IN THE HIGH AND LOW AREAS OF SASSEVILLE'S ORCHARD (Near Fairburn, GA)

These analyses indicate that the samples are essentially identical, except for the slight differences for Ca, V, Na and Mg that are noted. Thus, it is possible to conclude that, in this instance, the lack or presence of elemental species that could contribute to this condition is not an apparent factor.

In a separate experiment, a comparison of Rp, trunk circumference and a visible estimation of the percent of live branch wood was made. Table 4-III compiles this information. It is indicative that those trees located in the "low" area of the orchard are more hardy than those in the "high" area. However, no single factor has been recognized (at this time) that could be attributable to tree condition.

4.2.2.4 <u>A Study on Computer-Predicted Tree Health</u>: In a very cursory examination, a mathematical interpretation was made (NOTE 4-5) to predict tree health by the following equation:

$$H' = a_1 + a_2 p = a_3 p^2 = a_4 h + a_5 h^2 + a_6 Z + a_7 Z^z \qquad (1)$$

The constants, a_1, a_2, etc., were obtained from a regressive series fitted to sixteen sets of observed data (the impedance measurements of 16 trees from the SASSEVILLE Orchard). The index of correlation is 0.83 of the estimated tree health (according to the impedance measurements). The most important variable is impedance A; it accounts for approximately 50% of the predictability. Next is the height, h, of the branching point; a value of 40% is assigned to its predictability.

Table 4-IV summarizes the data obtained from this mathematical approach. The most significant aspect of this information is that all but two of the predicted values (tree nos. 6 & 7) are in excellent agreement with the observed impedance measurement data. Obviously, this interpretive approach requires more study.

4.2.3 <u>Preliminary Studies on An Inductive Measurement Meter:</u> As our work progressed, speculation was given to the potentials of using some form of inductive measurements, so that some of the possible complications which

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NOTE 4-5: Achnowledgement is given to L. C. Young, Physical Sciences Division, Applied Sciences Department, for this interpretation.

TABLE 4-III

COMPARISON OF Rp, TRUNK CIRCUMFERENCE, AND

ESTIMATED % LIVE BRANCH WOOD FOR

HIGH AND LOW AREA TREES

HIGH AREA

Rp	CIRCUMFERENCE	ESTIM.% LIVE WOOD
15.6 kΩ	31.43 cm	80%
21.7 kΩ	29.85 cm	30%
21.8 kΩ	29.53 cm	80%
23.7 kΩ	26.99 cm	40%
24.1 kΩ	29.85 cm	70%
27.6 kΩ	35.56 cm	45%
31.9 kΩ	24.45 cm	70%

LOW AREA

Rp	CIRCUMFERENCE	ESTIM. % LIVE WOOD
13.7 kΩ	46.36 cm	100%
15.0 kΩ	41.59 cm	95%
15.8 kΩ	38.42 cm	80%
16.1 kΩ	33.66 cm	50%
19.4 kΩ	36.20 cm	50%
20.5 kΩ	33.66 cm	60%
21.8 kΩ	38.10 cm	60%
22.9 kΩ	23.50 cm	35%
27.7 kΩ	40.32 cm	75%

TABLE 4-IV

LISTING OF TREE MEASUREMENTS, ESTIMATED % HEALTH, AND (COMPUTER-) PREDICTED HEALTH

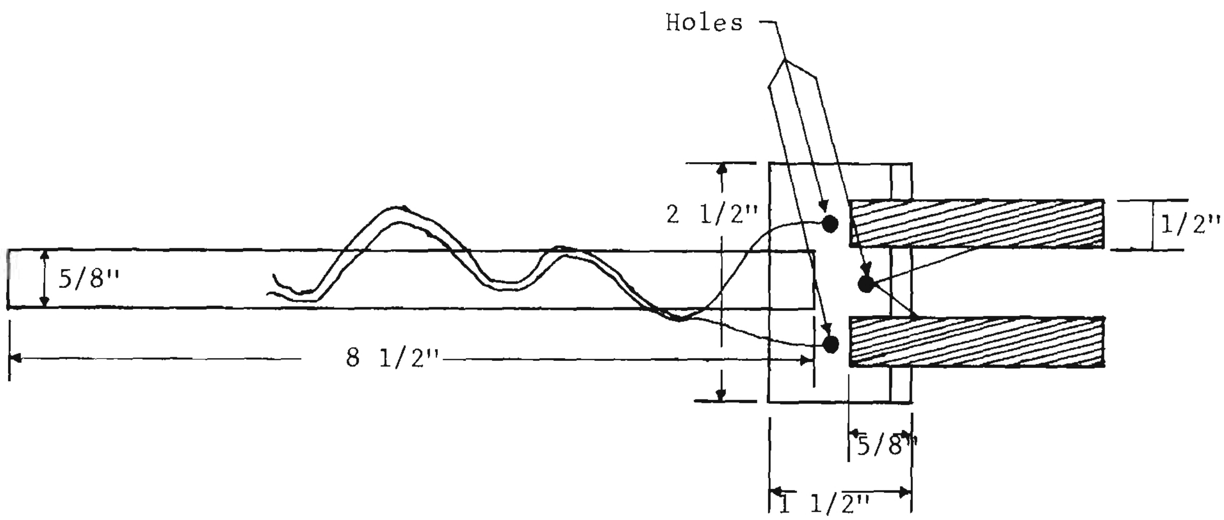
TREE #	PERIMETER	HEIGHT	IMPEDANCE	%HEALTH	PREDICTED HEALTH
5	29.85	41.91	21.6	30	33.9
6	26.99	20.32	23.6	40	59.3
7	29.53	33.02	21.7	80	55.5
8	31.43	27.94	15.6	80	82.3
9	35.56	40.64	25.4	45	52.3
10	29.85	22.86	24.1	70	65.5
11	24.45	50.80	31.9	70	67.0
17	38.42	35.56	14.6	80	83.4
18	41.59	24.13	14.9	95	90.4
19	46.36	22.86	13.6	100	100.8
20	33.66	8.89	16.1	50	49.5
21	33.66	33.02	18.9	60	61.1
22	40.32	13.97	27.6	75	76.4
31	36.20	35.56	19.3	50	56.3
32	38.10	15.24	21.8	60	52.3
33	23.50	40.64	22.8	35	34.3

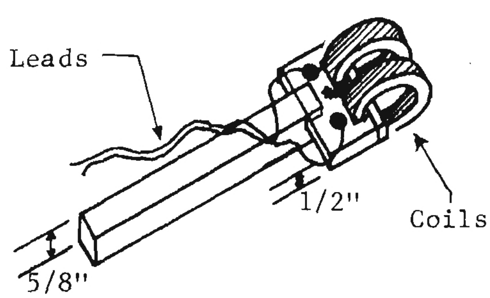
might result from the use of a conductive technique would be eliminated. For example, among the possible undesirable influences on a conductive probe system are such parameters as (1) the immediate presence of and the variability in length of an apparent plant response or shock period after the probes had been inserted into the tree tissue (many of the FIGURES displayed earlier show irregularity at the beginning of long time plots of R_p; also, rapid change in the "D" values were apparent) and (2) the possibility of electrolytic reactions at the probe and tree tissue interface, which would alter the R_p or impedance readings.

To measure tree tissue parameters inductively, preliminary tests were conducted using a double coil on treated paper. Both laboratory measurements and field measurements were made on five trees (four maples and one hickory seedling). The results were encouraging, although there was evidence that humidity might be influencing the readings, especially through the coil form.

The coils were then remounted in a plastic holder in the manner shown in FIGURE 4.2/23. After this coil arrangement was established, other laboratory and field test measurements, were made. These are summarized in Table 4-V. Initially, only ΔQ was measured; however, a capacitance value is possible and Δ_{cap} was recorded in later readings. Probe measurements were made using a capacitance value and "D" value. The "D" value is the same as a reciprocal "Q" value. Although the Q and capacitance values in the earlier (conductive) measurements are not the same (since the circuit was different) as those of the inductive measurements, it is interesting to note that both Q and capacitance measurements can be made by both methods.

It would be desirable to make field measurements in peach orchards by an inductive means; but, there are some difficulties. The "Q-meter" used was cumbersome and required an electrical energy of 50 watts at 125 volts. For rapid field measurements in orchards, a small solid state instrument would be more desirable. Some measurements have been made at 36.2 kHz but the most desirable frequency has not yet been determined.





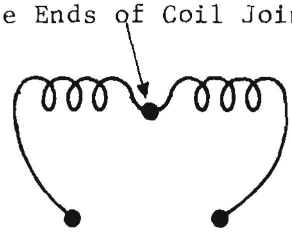


FIGURE 4.2/23 INDUCTIVE COIL USED TO MAKE MEASUREMENTS

TABLE 4-V

COMPARISON OF CONDUCTIVE MEASUREMENTS MADE WITH TWO INDUCTIVE COILS
(Field Measurements on Various Types of Trees)

With 1st Coil Type: Sept. 26, 1973			With 2nd Coil Type; October 3, 1973		
	ΔQ	Δ cap.		ΔQ	Δ cap.
#2 large Silver Maple South side trunk	11	Not Measured	#2 (southern) Silver Maple trunk, south side	6 10 20	6.1 5.1 9.2
Repeat above	6		Another trunk position	35	6.1
			On limb - removed area	30	5.1
			North side trunk (sp. A)	22	6.1
			Recheck trunk at S side	9	5.8
			Limb East side Big E limb	15	6.0
Hickory seedling N 6 feet up trunk	20		Hickory seedling trunk 24 feet	10	1.4
			Same higher on trunk	30	2.6
#1 (northern) Silver Maple (S) trunk	6		#1 (northern) S. side Silver M. trunk	38	4.8
Repeat	3		Repeat above (S. trunk	42	4.0
Repeat	5		Same tree, West side trunk	25	6.5
Large limb bark off	7		Same tree, North side trunk	30	2.6
5/8" diam limb	7		Same tree, rechedk N trunk	25	3.1
#1 (S) small maple trunk	11		#1 (S) small maple Southside trunk	13	10.4
1" + diam limb	12		Same small Northside trunk	32	4.8

TABLE 4-V

(continued)

With 1st Coil Type; Sept. 26, 1973	ΔQ	Δ cap.	With 2nd Coil Type; October 3, 1973	ΔQ	Δ cap.
			Small Small limb on East	10	2.1
#2 (N) small maple trunk	17		#2 (N) small maple South side trunk	14	2.9
1" diam limb	11		Same North side trunk	19	4.5

Placing a coil about the trunk or limb of the tree when a measurement is being made (in contrast with the current method of bringing the coil quite close to or in contact with the tree part during measurement) is possible. However, this method has several disadvantages. First, with the transport of ionic solutions within the tree in a vertical direction (or parallel to the axis of the trunk or branch), the most sensitive measurement should be made with the field force lines of the coil at a right angle to the transport direction. For this condition, the coil turns must be parallel to the ion movement since the field force lines are perpendicular to the coil windings. Thus, the axis of the coil should be perpendicular to the ionic movement. Second, it would be desirable to have the coil windings close to the tree for each measurement: adjusting the size of the coil around various sizes of tree parts appears, at this time, to be difficult. Third, placing the measuring coil about the tree for each measurement would create a slower analysis process so that rapid measurements of a large number of trees would not be possible. However, at the present time, it appears from this experimental work that an inductive measurement technique could be used readily once some of the mechanics of the process have been worked out.

4.2.4 Some Conclusions From This "Vitality" Meter Study: The data presented in this Section 4.2 has shown that a "vitality meter" using the principles of biopotential magnitude and pattern distribution is possible. However, more work needs to be carried out to study such factors as these:

1. Basic plant viability
2. Electrode polarization (instrument-induced electromotive effects)
3. Temperature
4. Lignification of plant cell walls
5. Changes in moisture content of plant
6. Electrode induced injury
7. High current density adjacent to electrodes
8. Electrode separation (stem length)
9. Stem diameter
10. Electrode contact resistance
11. Electrode lead effects
12. Non linear recovery effects from severe but non-lethal exposure

Most, if not all, of the theoretical and experimental work reported in the literature (some of which has been cited) has been directed toward the study of basic biological properties of plant life (albeit related to effects of injury). That is to say the instrumentation and techniques studied (and reported) are limited to those necessary for examining the fundamental characteristics relating to biological injury. Though very much applicable, these measurements are not the same as those required for applied field use.

Laboratory (and, as applicable, field tests) study efforts need to be designed and carried out on each of the factors listed above. For example, with respect to #2, "Electrode polarization", experiments need to be designed to include such tests as these:

1. The operation of electrodes (e.g. Ag/AgCl) in a reversable condition (i.e. no current flow) to minimize polarization.
2. The relationship of electric polarization to decreases in frequency to cause impedance magnitude to increase.
3. By measuring impedance as a function of electrode separation and extrapolating data to zero separation distance. It should be possible to determine the effective electrode impedance and consequently the effect of interference due to electrode polarization.
4. A study of the magnitude of polarization effects at low frequencies; the impedance phase angle should become negative (at about 50 Hz according to one investigator).
5. An investigation of the primary polarization effect below 200 Hz (and less than 10%) at all frequencies.
6. MnO_2-C conducting paste has been used on electrode studies on the way to reduce polarization, through the use of such conducting pastes as MnO_2-C.

Similarly, we believe that an understanding must be obtained on such parameters as basic plant vitality at low temperatures (Factor #1) and non-linear recovery effects from severe but non-lethal exposure (Factor #12).

These could involve studies on:

1. The linear relationship between conductance ratio (at two frequencies) and cold hardiness. This relationship seems to be linear except for such anomalous injuries that follow non-lethal frost exposure.
2. Methods to overcome the major barriers to electric current and ion movement at low frequencies (high frequency currents are not impeded) since cellular membrane acts like a leaky capacitor.
3. A determination of the degree of independence that Z_{NF} has from frequency (Θ) as plant tissue is destroyed.

Generally, electrical conductance will decrease as hardiness increases (this is consistent with increase in permeability of a membrane as hardiness develops), and normalized impedance (Z_N at frequency F) can be computed as

$$Z_{NF} = \frac{Z_f - Z_{500\ \mathrm{kHz}}}{Z_{500\ \mathrm{kHz}}} \tag{2}$$

Where Θ is independent of length and Z_{NF} is proportional to length. When measuring Z at only one frequency, changes may result due to lignification of cell walls, changed moisture content, or changes in electrolyte concentration.

Complementary to the intents expressed above is a need to <u>fully</u> investigate the potentials of an inductive measurement system. Very little work has been done in this area; in fact, we have not found any literature information that would suggest there are ongoing programs in this area.

4.3 THE USEFULNESS OF ELECTRONICS IMAGE ENHANCEMENT FOR "PEACH TREE DECLINE" STUDIES

In a research effort that was separate from the Applied Sciences Department's interest in sensor technology and measurement techniques, the STATION's Systems and Techniques Department carried out (NOTE 4-6) a project on infrared photography and electronic image enhancement methodology to study "peach tree decline". A general description of this methodology follows; a more extensive review of this project has been published (257).

257) SPANN, G. W. et al., "Infrared Photography of Peach Short Life Sites in Georgia", p. 29-42 in Proceedings of the 4th Biennal Workshop on Color Aerial Photography in the Plant Sciences and Related Fields, Univ. of Maine, Orno, July 1973.

4.3.1 Methodology - Electronic Image Enhancement: The use of electronic image enhancement had proved highly successful in studies of other agricultural diseases such as the corn blight in 1970 and 1971. Because of known past successes in closely related agricultural areas, the ENGINEERING EXPERIMENT STATION offered to enhance electronically some of the aerial photographs taken of Georgia peach orchards to demonstrate the feasibility of using such methods for studying peach-tree decline.

A typical system for the electronic enhancement of photographic imagery consists of a television camera for an input, a computer for processing, and a television monitor and/or computer printer for output of the results. The infrared transparency is viewed by the television camera and the information in the image is transformed into a digital code (by use of a densitometer) so that it can be computer processed. Once the image is stored in the computer memory, various statistical processing techniques can be employed. The technique used in this study in known as multispectral density slicing, a form of spectral pattern recognition which, in effect, sorts out areas of the image which "look alike" to the computer. This process is very similar to the human process of recognizing and sorting objects by color differences.

Once this statistical processing has taken place, areas of the image which have similar characteristics (or "look alike") are placed in categories representing healthy trees, several stages of declining trees, dead trees, and bare ground were examined. Two output media were used: a color television to display one or more categories at a time; and a computer printout to outline certain features. The TV-screen outputs could be photography.

NOTE 4-6: By G. W. Spann of S & TD's Physics Branch

The actual processing of the peach orchard imagery was accomplished using General Electric's Image 100 System. The major advantage of using this system for the feasibility study is that it allows the results to be displayed rapidly on a color television monitor. Permanent records of the results were made by photographing the screen and by obtaining computer printouts.

4.3.2 Results: The results of this study to date indicate that electronic image enhancement is a useful tool for studying peach tree decline. Identifications of healthy trees and trees in various stages of decline have been possible. The dead trees fall into a different category when observed in this manner.

These results do not tell the whole story, however, In the enhanced imagery some of the trees which appeared healthy when viewed on the ground exhibit characteristics similar to some of the diseased trees. After the imagery has been processed, for example, some trees rated as healthy appear healthy on only half of the area of the tree whereas the other half of the tree appears similar to the diseased trees. Thus, more levels of decline may be visible in the enhanced imagery than in the color infrared photographs.

This last feature - the ability to identify the many stages of decline - may prove to be the most useful application of electronic enhancement. If the declining trees can be identified early enough perhaps the cause of the disease can be more readily determined. Possibly this could lead to the discovery of some cure for this disease which threatens to destroy the Georgia peach industry. Additional studies will be made to determine how early the decline can be detected by this method.

4.3.3 Conclusions: There are several conclusions which can be drawn from this preliminary analysis.

(1) It is feasible to use electronic image enhancement to study peach tree decline.

(2) The healthy trees and those in various stages of decline can be differentiated.

(3) It may be that this methoc provides a means of detecting the decline earlier than other method.

(4) If further study shows that this method can identify the decline early enough, perhaps the cause and cure can be determined.

The analyses which have been carried out so far indicate definite promise for this method of studying peach tree decline. (NOTE 4-7). However, application of this technology is not limited to peach tree studies. Any agricultural crop which is subject to disease and insect damage could be studied by this method.

NOTE 4-7: Complementing this technique with "ground truth" studies by use of the "vitality meter" described in Section 4.2 should provide a unique capability for agricultural research.

5.0 RECOMMENDATIONS FOR FUTURE WORK BY THE ENGINEERING EXPERIMENT STATION

A continuing STATION research program to develop sensor, controls and measurement techniques for agricultural problems is recommended. The results of the activities described here have shown that EES has expertise and resources that could be used in worthwhile assistance to Georgia agriculturists. Many problems exist (as stated in Chapter 2) and many more will become evident as an earnest activity in this interest area is carried out.

The progress of the STATION's efforts will be marked by its future intents to increase its efforts in this area. If it proceeds with such program interests, it will need to continue to create collaborative activities with the various agricultural groups in Georgia and it will need to work more extensively with these groups to establish funding from state and federal agencies and from private foundations.

APPENDICES

APPENDIX A

<u>SELECTED PUBLICATIONS USED IN</u>
<u>"STATE-OF-THE-ART" EVALUATION OF</u>
<u>SENSOR AND MEASUREMENT TECHNOLOGY FOR</u>
<u>AGRICULTURAL PROBLEMS</u>

AGRICULTURAL ENGINEERING

AGRONOMY JOURNAL

AMERICAN JOURNAL OF BOTANY

BIORESEARCH INDEX

BIOSCIENCE

BIOSCIENCE ABSTRACTS

CANADIAN JOURNAL OF BOTANY

CANADIAN JOURNAL OF FORESTRY RESEARCH

CANADIAN JOURNAL OF PLANT SCIENCE

COMPENDEX (ENIMA)

ELECTRONICS WORLD

EXPERIMENTAL HORTICULTURE

FOOD TECHNOLOGY

FOREST PRODUCTS JOURNAL

FORESTRY ABSTRACTS

FORESTRY SCIENCE

HORTICULTURE ABSTRACTS

INSTRUMENTS AND CONTROL SYSTEMS

JOURNAL, AGRICULTURAL RESEARCH ENGINEERING

JOURNAL, AMERICAN CHEMICAL SOCIETY

JOURNAL, AMERICAN SOCIETY OF HORTICULTURE SCIENCE

JOURNAL, BIOLOGICAL CHEMISTRY

JOURNAL, CHEMICAL PHYSICS

JOURNAL, DAIRY SCIENCE

JOURNAL, EXPERIMENTAL BOTANY

JOURNAL, MICROWAVE POWER

JOURNAL, SOIL SCIENCE

NATIONAL BUREAU OF STANDARDS CIRCULARS

NATURE

PLANT PHYSIOLOGY

POPULAR ELECTRONICS

SCIENCE

SOIL SCIENCE

THE FORESTRY CHRONICLE

TRANSACTIONS, AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

U. S. AGRICULTURAL RESEARCH SERVICE BULLETINS

U. S. FORESTRY SERVICE BULLETINS

WEEDS SCIENCE

WESTERN FRUIT GROWER

YALE JOURNAL OF BIOLOGY AND MEDICINE

APPENDIX B

AGRICULTURAL FARM ORGANIZATIONS
IN GEORGIA

AGRICULTURAL FARM ORGANIZATIONS IN GEORGIA

GA. AGRIBUSINESS COUNCIL
Frank Welton, Exec. Director
Clyde Greenway, President
332 Agriculture Building
12 Hunter Street, S.W.
Atlanta 30334

GA. ANGUS ASSOCIATION
Hugh Snider, President
Hampton 30228

Ga. Auctioneers Assn., Inc.,
Col.George D. Hand, Exec. Sec.
P.O. Box 9691
Atlanta 30319
Col. Warren H. Waldrop, Pres.
2270 Clairmont Rd., N.E.
Atlanta

GA. MTN. APPLE GROWERS ASSN., INC.
Mr. and Mrs. Dover, Managers
P.O. Box 371
Ellijay 30540

Ga. Assn. of Agricultural Fairs
Mrs. O. D. ("Sis") Hardy
P.O. Box 6826
Atlanta 30315
Bill Wells, Pres., Ga. Assn. of Ag. Fairs
Augusta Exchange Fair,
Augusta

Atlanta Produce Dealers Assn.
I. W. "Bud" Williams
Sunkist Growers
216 Administration Building
State Farmers' Market
Thames Road
Forest Park 30050

Univ. of Ga. Ag. Alumni Assn.
Hugh A. Ingliss, Sec.-Treas.
319 Hoke Smith Annex
Athens 30601
Earl Payne, Pres.
Swainsboro 30401

American Society of Ag. Engineers
J. G. Futral, Manager
Ga. Experiment Station
Experiment 30212

Atlantic Cotton Assn.
R. C. Walker, President
c/o Joseph Walker Co.
P.O. Box 11359
Columbia, S.C. 29211

Ga. Beekeepers Assn.
Troy H. Fore, Jr.
Secretary-Treasurer
P.O. Box 56
Gardi 31545

Georgia Canners Assn.
111 W. Taylor Street
Griffin 30223

Ga. Cattlemen's Assn.
J. W. Trunnell, Jr. Pres.
Cochran 31014

Ga. Cotton Ginners Assn.
Herbert Garrison, Pres.
Homer 30547

Cotton Producers Assn.
C. W. Paris, Exec. V.P. & Gen. Mgr.
P.O. Box 2210
Atlanta 30301

Ga. County Agents Assn.
J. E. Eubanks, Pres.
Court House
Louisville 30434

Ga. Crop Improvement Assn.
Harvey Lowrey, Ext. Agronomist
310 Hoke Smith Annex
Athens 30601

Ga. Corn Millers Assn.
Joe Kelly, Pres
c/o J. D. Perkerson & Sons
Austell 30001

Ga. Cotton Whse. & Compress Assn.
John D. Davis, Sr. Pres.
John Todd, Exec. V.P.
1085 Shrine Bldg.
P.O. Box 23
Memphis, Tenn. 38101

American Dairy Assn. of Ga., Inc.
W. R. Roberts, Pres.
315 W. Ponce deLeon Ave.
P.O. Box 216
Decatur 30031

Georgia Duroc Breeders Assn.
Freddie Deal, Pres.
Statesboro 30458

Georgia Egg Assn.
Perry McCranie, Pres.
Brookfield 31727

Georgia ACC for Eggs
Suite 118
1687 Tullie Cir., N.E.
Atlanta 30329
Roger C. McIntosh, Exec. Sec.

National Egg Co.
Joe Hamby
General Manager
1200 N. Buford Highway
Norcross 30071

Ga. Assn. of Ext. Home Economists
Mrs. Doe Harden, President
Zebulon 30295

Ga. Entomological Society
Robert Davis, President
Stored Grain Laboratory Products
Savannah

Southeastern Fair Assn.
Maurice Coleman, Gen. Mgr.
P.O. Box 6826
Lakewood Station
Atlanta 30315

Georgia Farm Bureau Federation
W. J. McKemie, Jr., President
2374 Ingleside Avenue
Macon 31204

Ga. Feed Assn., Inc.
Jim Boyd, Pres.
Carrollton 30117

Ga. Farmers Coop Council
W. L. Manton, President
North Ga. EMC
P.O. Box 1407
Dalton 30720

Foundations Seeds, Inc.
Bill Pritchard, President
Louisville 30434

Ga. Farm Equipment Assn.
Joe F. Pruett, Secretary
550 Riverside Drive
Macon 30201

Ga. State Florists Assn., Inc.
Betty Bass, President
Betty Bass Flower Shop
Columbus

Ga. Hatchery Assn.
Ray Burch, President
2515 Sewell Rd., S.W.
Atlanta 30311

Ga. Hereford Assn.
Bob Rush, President
Kathleen 31047

Ga. Hampshire Assn.
Edsel Lewis, President
Route 4-Box 106
Baxley 31513

Ga. Livestock Assn.
Franklin Smith, President
Route 2
Coolidge 31738

Ga. Milk Producers, Inc.
Rudolph Clark
Murrayville 30564

Ga. Independent Meat Packers Assn.
George Rogers, President
Rome Provision Co.
105 Polluck Street
Rome 30161

Ga. State Nurserymen's Assn.
Wayne Snow, Sr., President
Route 2
Chickamauga 30707

Georgia Peach Council
Hubert Hancock, President
Thomaston 30286

Ga. Pecan Growers Assn.
Mr. Shaw Fletcher, Pres.
Box 948
Americus 31709

Ga. Poultry Federation
George Cagle, President
518 South Enota Avenue
Gainesville, Georgia 30501

GFA Peanut Assn.
Perry M. Culpepper, Pres.
Cordele 31015

Southeastern Peanut Assn.
John W. Greene, Exec. Director
P.O. Box 582
Albany

Southeastern Pecan Growers Assn.
A. L. (Teal) Corte, Pres.
Loxley, Alabama

SE Poultry & Egg Assn.
Harold Ford, Exec. Sec.
1456 Lawrenceville Hwy.
Decatur 30030

Ga. Poultry Processors Assn.
Jimmy Burrus, President
Marietta
Ralph White, Sec.
P.O. Box 497
Gainesville 30501

Ga. Plant Food Educational Society, Inc.
Dr. S. E. Younts, Pres.
1649 Tullie Circle, N.E.
Atlanta 30329

Georgia Retail Council
Tom Gregory, Exec. V. Pres.
1022 Healey Building
Atlanta

Ga. Retail Food Dealers Assn.
Dexter Gatehouse, Managing Dir.
P.O. Box 10551, Sta. A
Atlanta 30310

Ga. Poultry Impr. Assn.
Soyd Strickland, Chm.
Chestnut Mountain 30502

Ga. Sweet Potato Impr. Assn.
A. A. Childs, President
Irwin County Growers Assn.
Ocilla 31774

Ga. Swine Growers Assn.
Lamar Trapnell, President
Statesboro 30458

Georgia Seedsmen Assn.
Rhodes Hardeman, President
Hardeman Seed Co.
Louisville 30434

Southern Seedmen's Assn.
John Meredith, Exec. Sec.
2036 Line Avenue
Shreveport, LA 71104

Ga. Assn. of Soil & Water Cons. Districts
Miller Dial, President
512-513 Grand Building
Macon 31201

Ga. Shorthorn Assn.
Oscar Healey, President
Healey Building
Atlanta

Georgia Spotted Swine Breeders Assn.
Preston White, President
Alamo 30411

Ga. Turkey Assn., Inc.
Richard Maul, President
Ila (residence)
University Coliseum
Athens 30601

Ga. Veterinary Medical Assn.
Dr. Horace G. Blalock, Jr.
2124 Highland Avenue
Augusta

Ga. Watermelon Growers & Dist. Assn.
Boyce Riddle, President
Montezuma

Ga. Yorkshire Assn.
Houston White, President
White Acres Farm
Hunter Road
College Park 30022

APPENDIX C

HARVESTING TECHNOLOGY

Harvesting Technology

A considerable amount of effort has been put forth in the last decade to develop hervesting machines for agriculture and horticulture. Many of these recent developments give much emphasis to rapid harvests and processing to get the materials in a more fresh condition to the marketplace.

Improvements continue to be made in harvesting machines for cereal grains, corn and field crops like cotton and tobacco. There has been an increased interest in having machines to harvest such materials as—

Okra	Almonds
Peas	Strawberries
Beans	Prunes
Cauliflower	Tomatoes
Cabbage	Apples
Potatoes	Peaches
Brussel Sprouts	Oranges
Onions	Grapes
Carrots	Pecans
Corn	Olives
Maize	Pears
Sugar Beets	Sugar Cane
Safflower	
Spices	

The references that follow give examples of the current state-of-the-art in harvesting technology.

Harvesting Systems

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APPENDIX D

INSECT CONTROL BY SONIC ENERGY

Insect Control By Sonic Energy

This appendix is used to report on a limited investigation carried out by STATION personnel (Note D-1) on the influence of sonic energy on insects, with particular emphasis on its potentials to control or eradicate cattle flies. Mr. Toler has provided this following information. The investigation suggests that there are some potentials for further studies in this area by STATION personnel.

NOTE D-1: J. C. Toler and G. M. Taylor of CD, Systems and Techniques Department

"In recent years there has been an increasing concern regarding the use of chemical insecticides for the control of insects. This has led to an interest in suitable alternate approaches that do not have potentially harmful effects on the environment. One alternate approach of interest has been the possibility of using infrasonic, sonic, or ultrasonic energy for insect control. To determine the feasibility of this approach, a limited investigation into the influence of these energy forms on insects was undertaken. The investigation was primarily directed to the influence of sonic energy on cattle flies, and consisted of an analysis of relevant reports and articles. These reports and articles were obtained by means of a literature survey that involved a manual search of U.S. Department of Agriculture publications and abstracts, a computerized search utilizing inter-university facilities at the University of Georgia, and telephone conversations with persons in the Agricultural Research Service of the U.S. Department of Agriculture.

Results of the literature survey indicate that very high sound intensities can be used to kill insects or to influence insect behavior [1]. The cause of death when very high intensity sound energy is used may be either direct damage to vital organs or by heat deposition. In either case, killing flies with high intensity sound energy appears impractical. The cost, according to Nelson [2], to produce the intensities required is quite large and the high levels may be unsafe for man and domestic animals, as reported by Lawrence [3]. These energy levels also can be maintained only in a restricted space and this introduces the problem of attracting the insects into small areas. If insects could be attracted to such a space, they could probably be killed by more economical methods, such as electric grids or microwaves. Therefore, using sonic and ultrasonic energy to influence the behavior of insects appears to hold more promise for practical control at the present time.

Studies of the specific behavioral response of flies subjected to sound environments has been limited and is generally inconclusive. It is known, however, that insects in general use sound for a variety of purposes, including congregating, mating, alarm, distress, protection by mimicry and defensive noise, and detection of sounds produced by predators and other dangers. The range of frequencies used is rather broad, ranging from sonic signals at approximately 100 Hz to ultrasonic signals as high as 200 kHz. Fruit flies as reported by Frings [1] and testse flies, according to Vanderplank [5], have been shown to use sound in their mating habits. Frings has also reported [4] that black flies exhibit a tendency to congregate at sonic frequencies and have shown a startle response at signals within this frequency range. Investigations with face flies and house flies have been contradictory. Brannon and Brown [6] reported positive repellent effects at sonic frequencies, while investigations by Kranzler and Earp [7] and Earp and Stanley [8] indicated no response by the flies when exposed to either sonic or ultrasonic frequencies. These experiments were performed by subjecting groups of test flies to moderately intense levels of sound, then sweeping the frequency range of interest while visually determining whether behavioral responses resulted.

The amount of literature surveyed during this search was reasonably large in spite of the fact that only a limited number of relevant reports were found. The review of these reports indicates clearly that (1) individual insect species use and respond to sonic frequencies unique to themselves, and (2) a valid approach to the study of sonic energy effects on insects should involve first recording and analyzing the sound emitted by the particular specie of interest.

The literature provided no indication that sounds emitted by cattle flies have been adequately studied. Such a study could be undertaken and would logically consist of (1) obtaining groups of cattle flies from government agricultural research centers, (2) recording the sounds emitted by these flies, (3) analyzing these sounds to identify predominate frequency components, (4) relating the predominate frequency components to certain behavioral responses, and (5) exposing the flies to electronically or mechanically reproduced imitations of their own sounds. In this manner, it could be determined whether the behavior of cattle flies can be successfully influenced by the use of sound energy."

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